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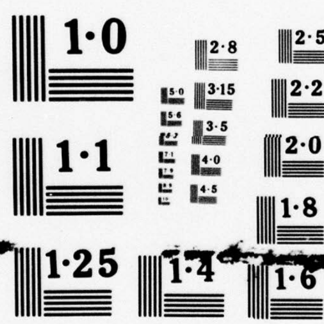
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Report No. CG-D-68-78

LEVEL II

INVESTIGATION OF EXTREME WEATHER OIL POLLUTION RESPONSE CAPABILITIES

13

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16. Abstract

This report presents the results of a study to evaluate the state-of-the-art and determine the feasibility of attaining an extreme weather pollution response capability. Sea states between 4 and 6 were considered. Investigations were made of systems for responding to stranding incidents, where the oil is still contained in a tanker, and for responding to oil spills. In the first case, cargo jettisoning and tanker stabilization methods were recommended as supplemental response techniques in addition to existing off-loading capabilities. In the second case, dispersant application from vessels and aircraft, and skimming with large (over 160 feet), dedicated skimming vessels, were recommended. Aircraft dispersant methods would provide response capabilities in sea state 6, and dedicated skimmers could work in sea state 5. The best existing skimming system is probably the Coast Guard's ~~skimming barrier, which would be~~ marginal in sea state 4.

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FOREWORD

This report presents the results of a study to examine the state-of-the-art and determine the feasibility of attaining an extreme weather pollution response capability. Seaward International, Inc., along with Hydronautics, Inc., and Searle Consultants as consultants, performed this work under Contract DOT-CG-80372-A, during the period 14 November 1977 to 14 July 1978.

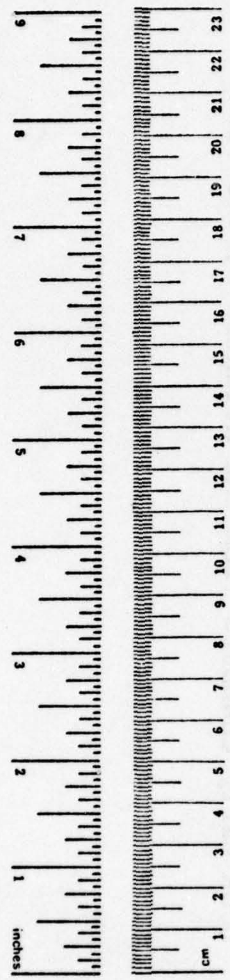
LCDR W. W. Becker and Lt. G.D. Marsh served as Project Officers during this program. R. L. Beach served as Project Manager from Seaward International, Inc. Investigators from Seaward included F. A. March, S. H. Shaw, R. P. Bishop, G. W. Ruetenik, and N. B. Davis. The principal investigator from Hydronautics, Inc., was W. T. Lindenmuth, who was aided by several staff personnel. W. F. Searle, Jr., from Searle Consultants, also contributed to the project. Many outside sources from industry and the Coast Guard made valuable contributions including, in particular, LCDR Barry Chambers from the Atlantic Strike Team.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

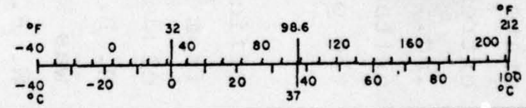
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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LIST OF ABBREVIATIONS AND SYMBOLS

B	Hull beam
C_B	Block coefficient for hull
c/co	Damping ratio for ship hull
dwt	Deadweight tonnage
f	Local freeboard
F_n	Froude number
G	Gravitational acceleration (32.17 ft/sec^2)
GM	Metacentric height
$h_{1/3}$	Significant wave height
k	Radius of gyration
K	Thousands of dollars
L, LBP	Hull length between perpendiculars
LOA	Ship's length overall
LWL	Hull length at waterline
M	Relative bow motion, RMS amplitude (Appendix D)
M	Millions of dollars
NE	Number of events per hour
RMS	Root-mean-square
SOA	State-of-the-art
V	Relative bow velocity, RMS amplitude
VOSS	Vessel of opportunity skimming system
T	Hull draft
T_n	Natural period
T_w	Wave period

1.0 SUMMARY

Extreme weather conditions that arise during open-water oil pollution incidents can severely inhibit or curtail conventional response operations. However, this report shows that the technology exists to improve this situation considerably, to the point of making certain response operations appear feasible in up to sea state 6.

The study began with a comprehensive examination of all of the variables and interactions that can affect response operations in high sea states or other extreme weather conditions. These included interactions between the oil, sea, atmosphere, personnel, vessels, aircraft, and other equipment. From these results the most important effectiveness considerations for an overall response system were determined to be: operational performance and system control, personnel, mobilization and set-up on site, support logistics, reliability and survivability, and any long-term environmental effects arising from a particular treatment method.

The study of actual response systems treated two separate operating regimes. The first is where the oil is still contained within the hull of a stranded tanker, and the second is where the oil has spilled onto the sea surface. Sea conditions from state 4 to state 6 were considered. The analyses of individual systems included consideration of effectiveness, time considerations (critical path networks for response events), and impacts on the Coast Guard in the areas of aircraft, vessels, manning, siting, and budgetary and supporting development requirements. Both state-of-the-art technology and new concepts were considered, as well as methods for solving problem areas and technology gaps within the state-of-the-art.

1.1 Regime 1

In Regime 1, the following major concepts were investigated:

1. Cargo off-loading using portable pumping systems.
   - A. Pumping into a barge or tankship.
   - B. Continuous burning with a flaring system.

2. Ship stabilizing using portable water-ballasting systems and moorings

3. In-situ burning of the cargo

A. By bombing and shelling

B. By planted explosives

4. Cargo jettisoning using ship's pumps.

The approach considered most likely to save the tanker, and thus most of the oil cargo, is to jettison part of the cargo immediately, thereby freeing the ship while all of her systems are intact. This should be done using the high-volume ship's pumps, but only while a tug is standing by to assist the ship when freeing occurs. For jettisoning to be attempted, there should be a high probability of success for the freeing operation, as well as a high risk of losing the entire ship if no immediate action is taken.

If jettisoning is not attempted, the next best alternative appears to be to ballast down the hull, flooding all available spaces, thus stabilizing the ship on the bottom. In this condition, the ship may be more likely to survive extreme weather until a full-scale salvage effort can be launched. Only relatively simple water pumping systems are required, although supplemental mooring systems for the tanker would also be desirable.

Portable pumping systems for off-loading cargo are relatively slow, and are considered to be best suited for off-loading leaking tanks, or as part of a general salvage effort. The use of these systems for jettisoning is considered infeasible. Major problems in off-loading during heavy weather are in controlling the ship, and in handling the receiving vessels. Flaring appears to be an attractive alternative to removing the oil by barge or tankship, but with present burning systems this process could be slow and hazardous in heavy weather. In-situ burning of the cargo appears to be a last-resort approach, because of the difficulties involved in bombing or with explosive techniques required to open up the tanks sufficiently to burn the oil.

1.2 Regime 2

In Regime 2, the major concepts for dealing with spilled oil were divided into two groups: skimming systems, and systems for "redistributing" the oil within the environment, such as by dispersing, sinking, or burning. In any technique, one of the prime requirements where personnel are concerned is to utilize large (160-foot or larger) seaworthy vessels, that will provide stable platforms for performing extreme weather tasks.

Several concepts for utilizing skimmers were investigated. These concepts deal mainly with the overall system approach to be used in attacking the skimming problem, rather than with the actual skimming mechanism (oleophilic surfaces, weirs, etc.).

The following skimming approaches were investigated:

I. Barrier systems

A. Skimmer independent of barrier

1. Distant-ship support (umbilical-supported, tethered to barrier -- Coast Guard OWORS/OWOCS)

2. Close-ship support (Skimmer mounted on a boom supported from ship)

B. Skimmer part of barrier

1. Integral skimmer and barrier (Coast Guard skimming barrier)

2. Non-integral skimmer and barrier (skimmer with herding barrier)

II. Direct-acting skimmers

A. Dedicated skimmers

B. Vessel-of-opportunity skimming systems (VOSS)

1. Pre-adapted vessels

2. Random vessels

From an ecological standpoint, skimming was considered to be preferable to redistributing the oil within the environment, but skimming can be a difficult and inefficient operation in high sea states, especially where thin slicks are present. Of the various skimming concepts, the use of a large catamaran or SWATH-type dedicated skimming vessel, utilizing a sorbent oil recovery mechanism, appears to be the most suitable for operations in up to sea state 5. However, no such vessels exist at present. Vessel-of-opportunity systems (VOSS) were less attractive, but they could permit independent operations with an over-the-side skimming mechanism that is decoupled from the motions of the support vessel. An outstanding VOSS skimmer concept was not identified, but several appear promising. Barrier systems were considered too unwieldy to be effective in high sea states, but the skimming barrier concept holds promise for sea states 4 and below. No other currently available skimming systems appear suitable for extreme weather operations.

Of the redistribution techniques, dispersants appear to be the most feasible. However, for thick slicks the results could be slow and costly, even with the use of self-mixing dispersants. Environmental considerations may dictate the use of other approaches in sensitive areas. Compared with the dedicated skimmer approach, dispersant techniques (air or vessel applied) appear to offer operational advantages, particularly with regard to logistics because a much smaller volume of material has to be handled. With regard to sea state, aircraft-application techniques are not affected by waves and responses in sea state 6 conditions would be feasible.

Slick sinking was considered ecologically unsound, and in-situ slick burning appears to be unfeasible in high sea states, even with confining booms.

Logistics for skimming operations could be simplified considerably if suitable on-site oil burning systems could be developed. Mobilization of oil receiving vessels (barges, tankships) and/or bulk dispersant supplies, and the transfer of recovered oil, equipment and supplies between vessels are critical steps in many of these operations.

1.3 Both Regimes

As a result of this study, several recommendations have been made, including the development of jettisoning and ballasting/stabilizing systems as additional response methods in Regime 1, and the development of large dedicated skimmers and dispersant application systems (both vessel and aircraft types) as primary response methods in Regime 2. Because dedicated skimming systems could require considerable development time, VOSS skimmers should be developed to provide a more immediately available skimming system in addition to the skimming barrier. Dispersant application systems exist already, but procedural and administrative problems inhibit their usage. Also, large-scale logistics systems for dispersants are not available.

Other recommendations include developing decision-making procedures for guidance in selecting the best response technique, investigating improvements to the Coast Guard's salvage capability, and developing flaring systems to dispose of recovered oil on site.

2.0 INTRODUCTION

This report presents the results of a study to examine the state-of-the-art in extreme weather oil pollution response methods, and to determine the feasibility of the Coast Guard attaining an extreme weather pollution response capability.

This study is one of four that were conducted by the Coast Guard as part of the response to the presidential initiative of March 1977. In the President's March 17 message to Congress, he established the goal of being able to respond to a 100,000-ton spill within six hours. Although major oil spills such as this can occur in any type of weather, extreme weather conditions are frequently encountered in oil spill situations, and in many instances have contributed directly to the casualty occurrence itself (tanker groundings, collisions, etc.)

The term "extreme weather" encompasses a wide range of weather conditions, involving wind and waves, temperature extremes, and precipitation. For this study, the wind and wave conditions, as categorized by the sea state designation, were considered the most relevant and difficult to cope with in pollution response operations. In particular, the minimum sea state considered was sea state 4, which can be characterized by an average significant wave height ($h_{1/3}$) of approximately 7 feet, when fully developed in a 20-knot wind. Sea states 5 ($h_{1/3} \approx 10$ feet) and 6 ($h_{1/3} \approx 16$ feet) were also considered. Some evidence[1] exists to indicate that above a sea state 6 an oil slick per se will not exist, and therefore clean-up attempts would not be feasible or justified. The other weather conditions assumed in the study were also adverse, but did not represent extremes, such as low temperature arctic operations, etc.

The types of response operations that were considered can be classified into two regimes. Responses to ship or barge casualties, where the oil is still contained in the tanks, were categorized as

Regime 1 responses. Regime 2 is where the oil has already spilled onto the sea surface, either from a vessel casualty or a well blow-out, etc. The object of responses in Regime 1 are to prevent a spill or to otherwise mitigate its effects. A wide variety of casualty occurrences could result in pollution incidents, as listed in Table 1.

Both state-of-the-art response concepts and new concepts were considered in each regime. State-of-the-art is defined as an approach presently in use or in advanced development, suitable for larger open-water oil pollution incidents, but not specifically for the extreme weather conditions considered in this project. New concepts include systems or approaches in conceptual form only, or that are currently in early research and development stages. Gaps in the state-of-the-art were also identified, and methods and sub-systems were identified to fill them.

Many of the systems considered in the two regimes have common problem areas, such as the need for adequate towing and support vessels, barges or other oil receivers, transfer methods for liquid cargos, handling facilities, etc. These systems are discussed in a section on general considerations for both regimes.

The study began with an investigation of the variables and constraints that could limit response operations in high sea states. These variables were then considered during investigations of the various response system concepts in Regimes 1 and 2. After weighing the relative merits of the various systems, the most promising from a technical standpoint were identified for each regime. The impacts that each of the systems would have on the Coast Guard, if the system were adapted as a response method, were then assessed in terms of vessels, aircraft, siting, manning, and budgetary requirements. Finally, the systems recommended for further development were identified. These steps are discussed in the following sections.

TABLE 1. CASUALTY SITUATIONS

Tanker or barge related

1. grounding: with or without holing

   a. sand
   b. mud
   c. coral
   d. rocks
   e. impalement - 1) rocks
      2) wreckage or other structure

2. collision: with or without holing

   a. between ships
   b. with structure (bridge, nav.aid, piers, icebergs)

3. hull rupture

   a. from external cause (other than grounding or collision)
   b. from internal cause (structural failure - hogging, sagging, corrosion, fatigue, etc.)

4. fire

5. explosion

6. sinking

7. power loss

8. flooding

9. breakup in heavy seas

Other:

1. well blowout

2. pipeline rupture

3. offshore terminal accident

3.0 INVESTIGATION AND UTILIZATION OF VARIABLES

There are typically many problems that occur during the conduct of response operations in extreme weather. Each problem can usually be identified with the interface activities between two or more elements of the situation, such as personnel with vessels, oil with skimmers, etc. The multitude of elements can be divided into eight general element groups, as shown in Table 2. Some overlap naturally exists between certain elements. For example, certain ship-board machinery could be considered either as Fixed Objects and Machinery, or as Floating Objects and Vessels. In this case, the particular interface activity under consideration determines how an item is best classified.

Any response operation in extreme weather must take into consideration the interface activities between the eight general elements of the situation. A successful approach for a given weather situation will involve resolution of all or most of the anticipated major difficulties, usually through careful planning and equipment and system design. Therefore, a thorough knowledge of both the environment and the capabilities of response personnel and components is essential in the design and planning stages of a response system development effort.

As an aid to visualizing the relationships between the elements, each element can be represented as the node of an octagon, as shown in Figure 1. The lines connecting the nodes together represent the interfaces that occur between the elements. One or more typical interface problem areas are also printed along each line. The triangular-shaped lines at Floating Objects and Vessels, Fixed Objects and Machinery, and Personnel represent interfaces among elements of the same type, such as Personnel-to-Personnel etc. Altogether, 31 interfaces are represented on the diagram. Not all of the interfaces are of equal significance in any particular response operation, but all of them should be considered for potential problems.

TABLE 2. DEFINITION OF GENERAL ELEMENT GROUPS

1. Water - The sea itself and its contents, whether in its natural state or as modified by response operations. Also sea water used in processes (cooling, etc.)

2. Oil - The oil responsible for the pollution situation, whether it be cargo, bunker, etc.

3. Expendables - Any supply-type of item whose loss or consumption in certain amounts is usually tolerable, such as sorbents, dispersants, chemicals, burning agents, fuel (POL), potable water, food, clothing, etc.

4. Personnel - All people active in the response operations, including response personnel, vessel and aircraft crews, machinery and equipment operators, etc., as outfitted for their specific mission.

5. Fixed Objects and Machinery - All types of equipment, such as pumps, power supplies, skimmer machinery, large tools, etc. On vessels or aircraft, this infers equipment not normally associated with integral propulsion, control, or other similar functions. Also refers to fixed structures in the water (towers, platforms, etc.), and to the sea floor itself.

6. Floating Objects and Vessels - Ships, boats, containment booms, buoys, etc. Usually includes integral functions such as propulsion, steering, navigation, etc.

7. Aircraft - Fixed-wing planes and helicopters, along with their normally integral functions, such as propulsion, control, navigation, etc.

8. Atmosphere - The air and all of its contents, including wind, temperature, vapors, sprays, exhausts, precipitation (rain, sleet, snow, fog), sunlight and darkness, noise, sparks and lightning, clouds, etc. Includes air use in processing (combustion, ventilation, etc.) and breathing systems.

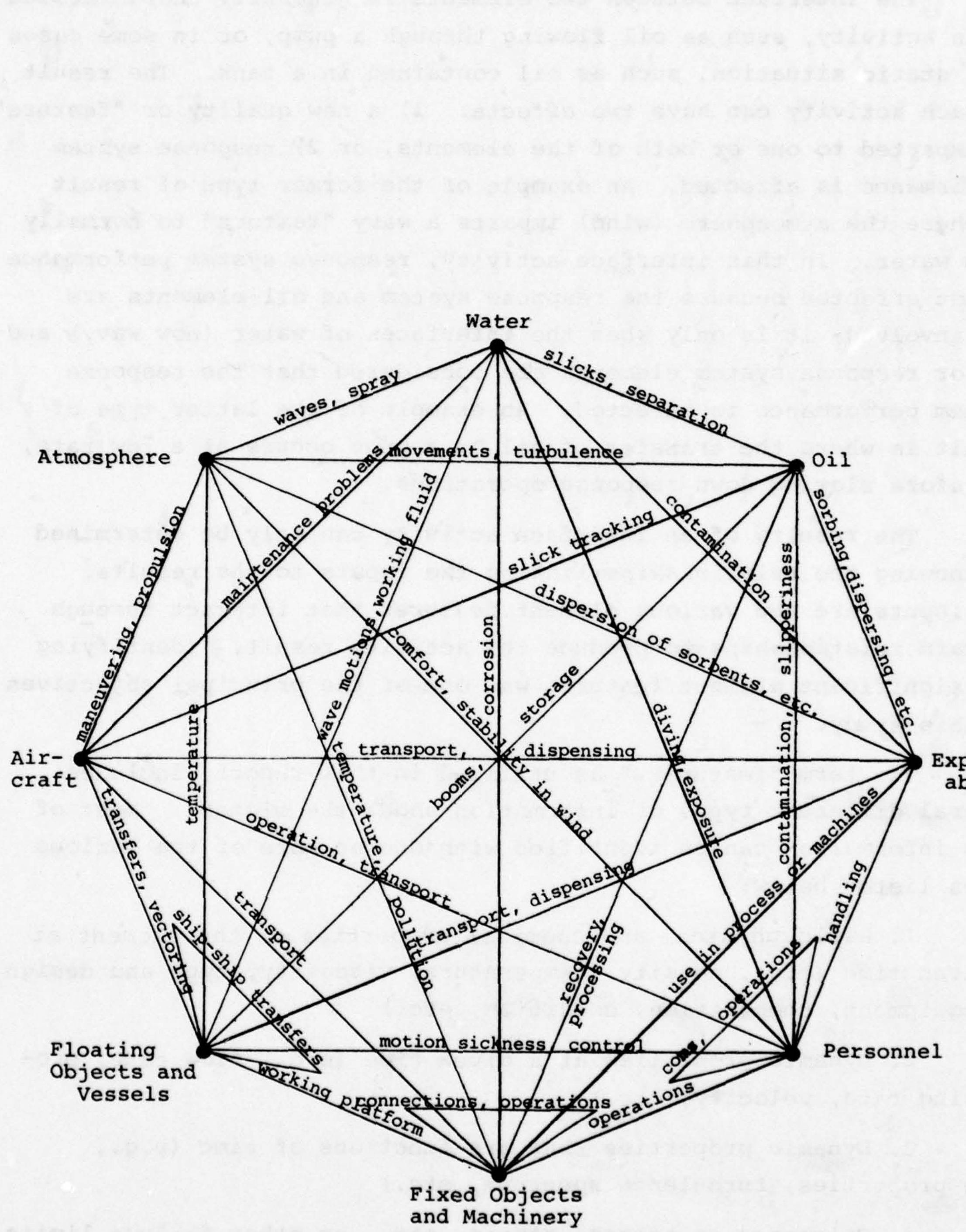


FIGURE 1. GENERAL ELEMENTS OF A RESPONSE OPERATION AND INTERFACES

The interface between two elements is generally characterized by an activity, such as oil flowing through a pump, or in some cases by a static situation, such as oil contained in a tank. The result of each activity can have two effects: 1) a new quality or "feature" is imparted to one or both of the elements, or 2) response system performance is affected. An example of the former type of result is where the atmosphere (wind) imparts a wavy "feature" to normally calm water. In this interface activity, response system performance is not affected because the response system and oil elements are not involved; it is only when the interfaces of water (now wavy) and oil or response system elements are considered that the response system performance is affected. An example of the latter type of result is where the transfer of oil by a pump occurs at a low rate, therefore slowing down response operations.

The results of an interface activity can only be determined by knowing the relationships linking the inputs to the results. The inputs are the various element features that interact through certain relationships to produce the activity result. Identifying the significant element features was one of the principal objectives of this study.

The term "features," as utilized in this report, includes several different types of information about the element. Most of this information can be identified with one or more of the various types listed below:

1. Basic physical and chemical properties of the element at a given time (e.g., density, temperature, viscosity, type and design of equipment, composition, condition, etc.)

2. Dynamic properties at a given time (e.g., flow rate, processing rate, velocity, etc.)

3. Dynamic properties that are functions of time (e.g., wave properties, turbulence spectrum, etc.)

4. Tolerance to stress, strain, etc., or other failure limits of an element (e.g., breaking strength, acceleration level where motion sickness occurs, etc.)

5. States of stress (or strain) of an element at any time (e.g., elongation of a strength member, emotional stress level on a person, etc.)

6. Quantities and availability of items under consideration at a given time (e.g., size or volume of an oil slick, number of aircraft of a certain type, etc.)

7. Capacity of an element (e.g., barge or tank capacity, saturation capacity of a sorbent, etc.)

8. Fraction of capacity utilized at any time (e.g., tank contents, etc.)

9. Special handling, safety or other requirements and procedures (e.g., needs for securing, aircraft operating procedures, need for protective clothing, etc.)

10. Other capabilities (e.g., personnel abilities such as sight, hearing, etc.)

The identification of features sometimes requires an iterative approach to be taken, in the sense that the results of an interface activity can impart a new or changed feature to one or both of the elements involved, and these new features can then be inputs to other interface activities which can generate even more new features. In this manner, the list of element features presented in the Appendix was generated.

One of the most significant elements of a response operation, and one which is not included in the diagram, is time. In many cases, where an interface activity affects response system performance, the effect is in the time required to perform the mission. Generally, three types of time effects result:

1. Performance is slowed down (e.g., a lower rate of oil skimming than desired, etc.).

2. Performance is delayed (e.g., an interruption of a critical operation, such as a minor equipment breakdown, temporarily halts progress of the response operation).

3. Performance is stopped (e.g., bad weather or loss of an irreplaceable component halts operations, etc.)

Table 3 indicates how the particular grade of task difficulty can affect time in extreme weather operations. As the weather worsens, the same task can become more and more difficult, increasing the severity of the time efforts.

These effects do not necessarily impede progress (except possibly for stoppage) unless the activity affected is on the critical-path of the operation. Even time effects from activities along the critical path are not necessarily crucial unless the target time is, for example, the time for an oil slick to reach the shore or other undesirable areas (Regime 2 responses), or the time when a stranded tanker is expected to break apart (Regime 1 responses). By their nature, such times are difficult to estimate, and any time losses by the response system could result in serious consequences. Certainly, activities that result in stoppage are the most critical, whereas the effects of slowing and delays can be more or less equivalent to each other.

Certain parameters of the casualty situation do not fit well in the framework provided by the eight general elements, and are listed separately in the table in Appendix A. These characteristics determine to a great deal the response approaches that can be taken with Regime 1 systems. Similarly, the geographic and human-use features associated with the land areas nearby also require separate consideration. Generally, geographic-type circumstances could be associated with setting of a target time limit for spill control (as discussed above), or in determining certain water currents and possible nearby wave conditions (shoaling beaches, etc.). Geographic considerations as they relate to the location of staging areas or supply depots, are significant and must be factored into the performance goals of the logistics-type response system elements (vessels and aircraft).

3.1 Sea State

As stated in the Introduction, "extreme weather" encompasses a wide variety of environmental conditions, including temperature and precipitation extremes, as well as extremes in wind and wave

TABLE 3. TIME EFFECTS OF TASK PERFORMANCE

Task Rate	Type of Task	Time Effect
A.	Easy, routine, or normal task for skilled personnel.	Standard time (base line)
B.	Must be performed slowly and carefully, but normally can be performed without incident.	Slowing of task performance time.
C.	Probability exists that task cannot be done, but performance is safe and would normally be attempted.	Possible delay or stoppage, but standard-time is also possible.
D.	Unsafe for personnel and only attempted in extreme emergencies.	Probable stoppage, or at best slowing or delay.
E.	High risk involved and would not be attempted.	Stoppage.
F.	Impossible tasks.	Stoppage.

conditions. However, by far the most common and significant weather factors are the wind and sea state conditions. Wind and wave conditions impact on nearly all aspects of a response operation including: delivery of equipment, personnel, and supplies; salvage; spill recovery; and slick burning, sinking, or dispersion. In regions of the sea coast where the oil spill potential is high, the weather will not be constant for very long, and sooner or later rough conditions can be expected, particularly during an extended operation.

A fundamental characteristic of sea conditions is their variability in response to changes in wind. As a result, safety considerations dictate that the response equipment should survive the worst probably conditions without undue hazards to personnel. Thus, a lower limit on the size of ships, barges and other floating (manned) response equipment is imposed on the basis of their seakeeping qualities.

In the case of Regime 2 response, where an oil spill is involved, the performance of oil booms and skimmers is degraded by wind and waves so that recovery may only be effected with specialized equipment and systems. Indeed, severe weather can act to disperse a slick into the water column so that recovery is virtually impossible (and perhaps no longer necessary).

The subject of limiting sea conditions for oil slick survival has been specifically considered recently in several related U.S. Coast Guard sponsored research studies.(1)(2)(3) Naturally, there is no single criteria that defines such a limit. Many factors are involved including oil film thickness, physical and chemical properties (which may change in time), and wave height and steepness. A general conclusion of this work is that natural dispersion of a slick by wave action requires waves to break within the slick at a sufficiently high frequency. Unfortunately, wave forecasting technology is not sufficiently developed to predict the frequency of breaking in open water, even without considering the oil layer effects on breaking.

Although it is difficult to define an actual Sea State limit, improved estimates of the range of limiting conditions are being made and verified. Presently 3 ft. is thought to be the lower limit of wave height at which the lightest oils begin to disperse. Current estimates of the upper limit of wave height, where even the heaviest oils are unlikely to remain in a slick, range from 8 ft. to 12 ft.(1) The fate of such naturally dispersed oil is not well known but it is clear that much of the oil will eventually return to the surface.

Some examples may serve to illustrate the difficulty in defining a limiting Sea State for slick survival. In the case of the Argo Merchant, the slick emanating from the vessel was intact during moderate 7 to 8-foot seas in 20-25 knot wind; however, a slight increase to 10-foot waves in 40 knot winds caused complete dispersion.(4) In the later condition, every large wave approaching the vessel was seen to steepen and break as a consequence of the local shoaling in water depth. Oil from the Torrey Canyon formed a stable water-in-oil emulsion or "mousse" that survived severe weather conditions. On the other hand, thin slicks have been completely dispersed by rainfall. Even large 100,000-gallon slicks have been reported to disappear in a few hours during short, severe storms with 6 ft. or higher waves.

While it is not possible to accurately define a limiting condition for slick survival (it seems clear that the extreme conditions considered in this study can exceed such a limit), we can affix limits on the size of vessels that may be considered for inclusion in a response system. Elements of seakeeping that have been considered include: vertical accelerations, deck wetness, roll response, and slamming.

Any operations (such as spill recovery) requiring personnel to be exposed on the foredeck in head seas or that requires station keeping or heading in beam seas is limited to significant wave heights on the order of 5 percent of the waterline length. This value was based mainly on consideration of deck wetness, which should be limited to only a few events per hour of taking green water over the foredeck during operations. Deck wetness, accelerations, slamming, and other seakeeping analyses are discussed in Appendix C. Thus, in terms of

the three (fully arisen) sea conditions being considered for Regime 2, limits on length are:

(Operate) Sea State	Minimum Ship Length*
4	140
5	200
6	315

In cases where operation is not sensitive to heading, vertical accelerations at the bow, and/or deck wetness at the bow, the minimum satisfactory length may be reduced to the corresponding limits for survival, viz. significant wave heights on the order of 17 percent of length:

Survival (Sea State)	Minimum Length*, ft.
6	92
6-7	115
7	165

At the other extreme in vessel size, very small inflatable boats (Zodiac-type) can be used for limited tasks in high sea-state conditions. However, their success depends on skilled (and daring) operators, and launching and retrieval operations are hazardous.

Sea conditions in general will have varying effects on response system personnel, depending on their degree of training, mission, and dedication to the job. As in battlefield situations or in other disaster responses, the efforts of only a few key personnel can sometimes determine the success or failure of a response operation. However, in our studies of response systems, only what we feel are nominal capabilities of trained individuals are factored into our recommendations. To down-rate a particular system because we feel that repair or hookup is difficult (or perhaps impossible), is not to say that it cannot be done by an extraordinary person given enough time. We do feel that the probability of success in performing these operations may be low, and in most cases would limit the applicability of the concept as a general response tool for the sea conditions under consideration. On the other hand, even operations that appear to be relatively simple may be difficult or

* Note: nominal values ±25% depending on ship details

impossible to perform because of the absence of personnel willing to attempt them, or because of extenuating circumstances that make the operation unusually risky. These considerations apply not only to response personnel, but to aircraft pilots and crews, tugboat operators, etc.

3.2 Scenarios

In this study, extreme weather pollution incident scenarios were used in evaluating the capabilities of various response systems and in identifying the situations where state-of-the-art systems were either deficient or would not work at all. To keep the system evaluation to a workable level of effort, the number of scenarios had to be limited. At the same time, the scope of the scenarios had to be sufficiently broad to adequately cover the spectrum of potential severe weather oil pollution incidents.

Analyses of the variables and other features that appeared to have the greatest bearing on extreme weather response systems indicated that the three elements of primary importance were oil volume or rate, oil type, and sea state. Scenarios were developed for both regimes using these elements as variables, as shown in Tables 4 and 5. Other significant elements were incorporated as constants, such as temperature, precipitation, etc.

In Regime 1, the size of the vessel was varied to cover the cases of a large barge and a medium-size tanker. The tanker size chosen was larger than any tankers that have been involved in actual or potential spills in U.S. waters in recent years, but it is still not large by today's standards. Larger tanker incidents would probably be approached by using multiple response system components, and, therefore, larger tankers need not be considered at this time. The possible combinations of oil type, sea condition, and oil quantity yield eight different scenarios for Regime 1.

In Regime 2, an oil spill rate was chosen, rather than an oil volume, because the rate is critical to the performance of all clean-up systems. The value of 1,000 gpm (approximately 200 tons

TABLE 4. SCENARIOS - REGIME 1

1. Oil Viscosity:	A)	Medium crude - 30 cs (0.87 s.g.)	
	B)	Heavy oil - 5,000 cs (0.95 s.g.)	
2. Sea Conditions:	A)	Operate:	10 m/sec wind, $H_{1/3} = 2.1$ m
		Survive:	15 m/sec wind, $H_{1/3} = 4.8$ m
	B)	Operate:	15 m/sec wind, $H_{1/3} = 4.8$ m
		Survive:	20 m/sec wind, $H_{1/3} = 8.5$ m
3. Oil Quantity:	A)	150,000-BBL Barge	
	B)	100,000-DWT Tanker	

4. Other Casualty Features:

- Locations: 25 miles offshore, 50 miles from nearest staging area, 200 miles from nearest major supply center
- Vessel grounded - holed - speed at grounding approx. 8 kts
- Vessel power systems inoperative
- List 10°

5. Other Environmental Features:

- Diurnal tidal current of 2 kts maximum
- Sea temperature $4^{\circ}C$
- Air temperature $0^{\circ}C$
- Intermittent precipitation
- Minimal debris present

TABLE 5. SCENARIOS - REGIME 2

1. Oil Viscosity: (on the water)
   - A) Medium crude - 30 cs (0.87 s.g.) initial; 400 cs (0.92) in 1 day: 2400 cs (0.97 s.g.) in 3 days.
   - B) Heavy oil - 5000 cs (0.95 sg) constant

2. Sea Conditions:
   - A) Operate: 10 m/sec, $H_{1/3} = 2.1$ m
     Survive: 15 m/sec, $H_{1/3} = 4.8$ m
   - B) Operate: 12 m/sec, $H_{1/3} = 3.0$ m
     Survive: 17 m/sec, $H_{1/3} = 6.0$ m
   - C) Operate: 15 m/sec, $H_{1/3} = 4.8$ m
     Survive: 20 m/sec, $H_{1/3} = 8.5$ m

3. Oil Rate: 1,000 gpm average outflow rate

4. Other slick features:
   - At 1 mile from source: thin slick, 2,000 ft. wide, with thickness 0.03 mm; 400 ft. wide windrow in center of slick, containing elongated oil pancakes 5 mm thick and 100 x 200 ft. area (90% of oil).
   - Wind/wave driven slick velocity 0.7 kts, in addition to tidal current of 2 kts. max.

5. Other casualty features:
   - Location: Same as Regime 1
   - Vessel grounded and holed

6. Other environmental features:
   - Same as Regime 1

per hour) is somewhat larger than the average spill rate that occurred during the Argo Merchant incident, but it is not an unreasonably high number (during the first week of the Amoco Cadiz incident the spill rate averaged 5,000 gpm).

The spilled oil properties would be likely to change with time because of weathering, and therefore, a change in viscosity and specific gravity of the medium crude oil was described in Table 5 to allow for this factor. The heavy oil was assumed to maintain its physical properties, although in reality, it too, would undergo some weathering.

Slick features are described at one mile from the source, for reference. At the source, the oil would be thicker and more concentrated, and at distances greater than a mile, additional spreading and slick break-up could be expected. The average slick velocity would be determined by wind velocity (typically about three percent of the mean wind speed) but a constant value was assumed here for simplicity. Even then, the diurnal tidal current would complicate matters, although this effect would be limited to an oscillation range of approximately eight miles. The actual state of the oil in a slick subjected to wind and wave action is dependent on many variables.

A vessel casualty was assumed for the Regime 2 scenarios, but the incident could just as well be a blowout, pipeline rupture, etc. The various combinations of oil type and sea conditions result in six scenarios for each system analyzed in Regime 2.

3.3 Response System Assessment Methods

The different response systems for each regime were assessed in various manners. Three major considerations were:

1. Overall technical effectiveness, as estimated in a rating method.

2. Time considerations, as indicated by investigation of critical path-type diagrams.

3. Impacts on various Coast Guard functions and existing equipment systems.

These assessments were considered, as applicable, in the description and discussion of each system.

3.3.1 Rating Method: To compare the various response approaches according to their overall effectiveness in dealing with a "nominal" casualty situation in each regime, a rating method was used. The rating method subjects the response system to a series of weighted effectiveness questions, with each "answer" being a numerical coefficient, C_i, indicating a certain degree of performance; a rating of $C_i = 1.0$ indicates good performance with no problems, a rating of $C_i = 0$ indicates anticipated system failure, and an intermediate rating indicates the anticipated degree of effectiveness between these extremes.

The questions are each weighted according to their respective importance by a factor w_i, where the sum of the w's for all of the questions equals 1.0. The overall rating, C_o, for n questions is then computed as:

$$C_o = C_1^{w_1} \times C_2^{w_2} \times \ldots C_n^{w_n}$$

This type of weighting function points out weak links in the system by giving the entire system a zero rating when any "answer" indicates an anticipated failure point ($C_n = 0$). (A straight weighted averaging yields nearly the same overall rating when individual ratings are sufficiently removed from zero.)

The rating categories are briefly discussed below. These descriptions are general, and are applicable to both Regime 1 and Regime 2.

Performance: (weight 0.30) The performance rating indicates the effectiveness in achieving the objective of the system once the equipment is in place and operating. It is a measure of capacity, efficiency, and the amount of undesirable side effects (such as secondary pollution) while operating in the environment

under consideration. The weighting is high, because this is the whole purpose for the system.

Operational Control: (weight 0.15) The rating for this category indicates the magnitude of the control problems to be expected in achieving desired performance. If few problems in controlling the system are expected, a high rating is given; if control is expected to be difficult because constant adjustment or especially close coordination is required to accomplish the objectives, a low rating is given.

Personnel: (weight 0.15) The rating for personnel indicates the degree of difficulty that trained system operators are expected to have in functioning in the environment under consideration. If no special problems are expected, because the vessel is stable or the work is not especially dangerous or demanding, a high rating is given; where parts of the job are hazardous or demanding, a low rating is given. This category is not weighted as high as "Performance," because in many cases the definition or design of the system has already taken personnel considerations into account (for example, the requirement for limiting manned skimmers or support vessels to lengths greater than 160 feet is largely a personnel consideration).

Mobilization and Setup: (weight 0.15) This rating indicates the complexity or degree of difficulty in mobilizing, delivering, and setting up the system, to the point of starting continuous operation. If such operations are expected to be of short duration, if transport and setup is easy, and if the required support functions are readily available, a high rating is given; if these operations are time-consuming, have a probability of not being successful, or are dangerous (here is where personnel considerations enter again), a low rating is given. The time factor is important here because the casualty situation can deteriorate rapidly in extreme weather, and mobilization and setup delays can mean a big difference in the effectiveness of the response operation.

Support Logistics: (weight 0.10) This rating indicates the magnitude of the continuous logistical support required during normal operations. The major considerations are the removal of recovered oil, the delivery of bulk materials such as dispersants, etc. A high rating represents an easy problem with few difficulties expected in securing supply vessels or in making transfers to or from the supply vessels; a low rating indicates that considerable difficulties are likely, including considerations of seakeeping, hazards, etc.

Reliability: (weight 0.05) This rating indicates the likelihood of experiencing key component failure, and also the magnitude of the ensuing problems if component failure occurs. If components are known to be reliable and simple systems are included, or if repairs can be rapidly made if failure does occur, then a high rating is given; if reliability is low, or if the system is complicated with a long chain of key components tied together, or if a failure cannot be rapidly repaired in place, a low rating is given.

Long-Term Environmental Effects: (weight 0.05) This rating reflects the problems resulting from introducing new substances into the marine environment, as might occur during part of the response effort (dispersants, etc.), or as a result of redistributing the oil within the environment (sinking, dispersing, etc.). Such problems are quite subjective in most cases, and involve political as well as ecological considerations. They are also sensitive to local environmental considerations, which are outside the scope of the scenarios. Therefore, although such problems could be far reaching, their lack of specific definability entails that they be given a relatively low weighting at this stage. In general, a low rating is given to approaches that deliberately add new materials to, or keep the oil within, the water environment, and a high rating is given to approaches that attempt to remove all pollutants.

Survivability: (weight 0.05) A high rating is given to systems that are likely to survive extreme weather conditions with no damage, or that could likely be returned to service rapidly if

damage does occur, and a low rating is given to systems where survival without significant damage is improbable.

3.3.2 Time Considerations

For some of the systems, time-line diagrams were constructed and examined for critical-path considerations and bottlenecks. These diagrams (Appendix D) included examples of the major activities that could take place from the first notifications of a spill or potential spill incident to well into the response process (cleanup, off-loading, etc.). Estimated times were assigned to each activity, and the sequence of activities was diagramed in a typical critical-path manner. Much of the estimating was subjective, because of the dependence of many of the activities on local availability of equipment systems, etc.

3.3.3 Impacts on the Coast Guard

The major systems are discussed in terms of the following impacts on the Coast Guard:

1. Vessels
2. Aircraft
3. Equipment siting
4. Manning
5. Budgetary factors

Vessels: Primary emphasis was given to Coast Guard vessels where they may be applicable as support vessels for various functions. Naval and other government vessels were also considered, as well as various types of commercial vessels that might be chartered when necessary or contracted for on a long-term basis. Purchasing of new vessels was also considered where such vessels might be provided with a multi-use capacity.

Aircraft: Again, primary emphasis was placed on impacts to Coast Guard aircraft, if they appeared to be applicable in the system. Other military and commercial aircraft were also considered.

Equipment siting: The following items were considered in siting considerations if they were felt to be significant and definable:

1. Size and dimensions
2. Weight
3. Transportability
4. Cost (see budgetary requirements also)
5. Response time
6. Storage requirements

Only general considerations of siting locations are discussed, as much of this type of work is already being done in another Coast Guard study.(5)

Manning: Consideration of the following manning requirements were given if they were considered significant and definable.

1. Dedicated (full-time) personnel requirements
2. Cross-training requirements
3. Maintenance requirements
4. Technical support

Budgetary Factors: For state-of-the-art (SOA) systems (except for those presently in the Coast Guard inventory), acquisition costs and operations and maintenance costs were considered. Most SOA systems are not suitable for extreme weather operations in their existing configurations, and therefore, most system acquisition costs could only be estimated at this stage of conception. Development times and costs for both SOA systems and new concepts were considered in general terms, as described in the next section. Acquisition costs for new system concepts were also estimated where enough system definition could be provided.

Development Efforts: In this study, where many types of systems are considered, and a wide range of development efforts is required, it is useful to classify the anticipated development efforts into general categories, such as discussed above. With this approach, repetitive discussions on anticipated efforts may be avoided, and a better perspective will be provided for comparing alternatives.

The development efforts can be classified as follows:

1. Complete: The entire development process is involved, including the following general steps, the details of which may or may not be required in all cases:

a. Concept feasibility studies to define specific requirements and functions; evaluate competing approaches; perform small-scale and breadboard model testing; do initial layouts.

b. Preliminary design studies, including preliminary design and cost estimating; advanced model testing, or subsystems prototype development.

c. Contract design and/or advanced development; advanced model or prototype development and testing; detailed cost estimates.

d. Detailed system design and first article construction including integrated system testing; preparation of supporting documentation; support system acquisition.

2. Advanced: This requires the application and development of existing and proven concepts to special Coast Guard equipment and systems. Would probably include portions of steps b through d in the complete development effort.

3. Limited: This could involve the adaptation, redesign or final design of existing or well-developed large-scale systems for Coast Guard use. Would probably include portions of steps c and d in the complete development effort.

4. Minor: In this case, only small or minor modifications are required to adapt existing systems for Coast Guard use. May involve only the establishment of certain design parameters in otherwise standard designs. May include step d of the complete development effort, or possibly production could begin immediately after design.

Within each of these classifications, the expenditures of time and money could vary considerably. Therefore, to further classify the development efforts, the following breakdown of development cost and time duration was made. Although time duration and

cost are not necessarily related, the match-ups given appear to be reasonable for typical Coast Guard R & D projects.

<u>Development Expenditures for Coast Guard Systems:</u>

1. Major--Over $5M and 6 years duration.
2. Large--Between $1M and $5M, and 4-6 years duration.
3. Medium--Between $0.2M and $1M, and 2-4 years duration.
4. Small--Between $20K and $200K, and less than 2 years duration.
5. Minor--Less than $20K and 1 year duration.

4.0 REGIME 1

General Considerations

The object of the response operations in this regime is to prevent or minimize pollution from a stranded or damaged tanker. A stranding may not result in immediate leakage, but frequently structural damage occurs, which can make the ship more vulnerable to the stresses imposed by the sea and bottom conditions.

The basic consideration in a grounding is to protect the hull. Protecting the hull not only prevents or minimizes pollution but it also facilitates the ensuing salvage operations. Protection of the engine room is also an important consideration, as having ship's power available for off-loading the cargo is much easier than using alternative systems. However, from both a salvage and a pollution standpoint, a sound hull is the more important consideration.

Protecting the hull in a grounding situation usually entails minimizing the static and dynamic stresses on the hull, and stopping the working of the hull on the strand, which can tear the plating and damage the structural members. Tidal changes also contribute to changing loadings, which can impart further stresses to the hull.

The ultimate in protection comes from rapid removal from the strand, and towing (if necessary) to port. The time of exposure to adverse conditions is minimized, and the probability of extensive pollution is reduced.

A first consideration, if the ship's pumps are operable and the grounding is not too hard, may be to jettison cargo and free the ship. A quick and accurate appraisal of the cargo, ship condition, and bottom conditions must be made, and proper approvals must be obtained. For jettisoning to be attempted, there should be a high probability of success for the freeing operation, as well as a high risk of losing the entire ship if no immediate action is taken. Other Regime 1 response methods should also be considered at this time, but these will probably have lower chances of success in avoiding the loss of the entire cargo and vessel in extreme weather.

If jettisoning is not attempted in heavy weather, then the next consideration in protecting the hull before it can be off-loaded, pulled off, and towed away, is to stabilize it in one position and prevent it from working. One way of doing this may be to flood down available spaces (including the engine room, if necessary) to make the ship hard on the bottom. Even in good weather, cargo off-loading should be accompanied by equivalent water ballasting to keep the hull stabilized and protected in the event of changing weather or adverse currents. At the time of freeing, high volume salvage pumps can pump off the ballast water rapidly.

Ballasting down cannot always be achieved, because of peculiar bottom conditions or deep water around the point of stranding or because of insufficient spaces in which to pump the ballast water. In any event, the ship should be stabilized with moorings, tugs, salvage ships, or similar vessels.

In areas such as the Northeast, where tanker traffic is heavy and the risks of grounding are higher than usual, only a few days of good weather may be available in which to gain control of a stranded ship. The initial decisions on what to do must take weather forecasts into consideration, along with the time requirements for mounting controlled off-loading and salvage operations. The time required to off-load and free a large casualty will probably be too long to avoid weather problems (except for the case of jettisoning using the ship's cargo pumps), and therefore, provisions for initially stabilizing a stranded ship should be given high priority in Coast Guard contingency planning. Short of attaining a complete salvage capability, the Coast Guard's efforts may be best directed towards utilizing their quick response capabilities in providing rapid assessment of the situation, and in initially stabilizing the vessel until salvage efforts can be mounted.

In cases where tanks are breached and oil spillage is occurring, pollution can be mitigated by pumping the remaining cargo into sound tanks, if available. This can be undertaken as part of the ballasting operation, if ballasting is attempted. This is the type of operation for which the ADAPTS pumping system

is particularly suited. However, off-loading the cargo remaining in the leaking tanks to another vessel presents many of the same problems as a full-fledged off-loading operation. When dealing with relatively small volumes of oil, the portable, floating bladder concept is attractive. In any situation, however, if only limited resources are available, efforts should be primarily directed towards protecting and stabilizing the hull, in an effort to prevent problems of even greater magnitude later on.

Several historical efforts to off-load cargo from stranded tankers have eventually reached the point where the probability of success appeared to be zero. In this situation, more drastic measures, such as bombing or burning, have been tried with limited success. The future probability of success for these measures does not appear to be high, but in cases where extensive pollution has already occurred such methods appear attractive because of a "what do we have to lose" feeling on the part of response officials. The questions as to whether or not such operations should be planned for as a first line of defense has been addressed in this study, and the general conclusion is that conventional off-loading methods have a much higher probability of success, and that bombing or explosives techniques should remain as secondary considerations.

After a damaged vessel is freed, it should be removed from the vicinity as soon as practical, especially if rough weather is imminent. As all of the cargo may not have been removed by off-loading, some form of cargo stabilizing may be desirable to prevent further spillage in case of structural failures to sound tanks. A gelling method has been considered for this, but it is considered beyond the state-of-the-art at this time.

As stated above, the key to success in the initial stages of a response operation is the rapid and accurate appraisal of the ship and cargo situation. The objectives are to determine where and how hard the ship is aground, which cargo tanks are sound and which are leaking, how much cargo must be off-loaded from which tanks, and how much ballast can be added to which tanks. These questions require appraisals of the tank contents, structural integrity, and other considerations. Attempts are usually made to obtain some of this information, but with available techniques the

data gathering process is time-consuming and the conversion of this data into useful information is difficult. Thus, there are also "gaps" in the appraisal function, and these are discussed later in the report.

Response Techniques

Techniques that can be considered for dealing with a stranded vessel are described in the following sections. Other casualty types (collisions, power losses, etc.) sometimes have related problems, but if the vessels remain afloat, the problems of dealing with them (except in the case of fire) are usually not as severe. Descriptions of the systems are written around the scenario requirements presented as Table 4. Cargo gelling is also discussed as a new concept.

4.1 Cargo Jettisoning

System Objective

To rapidly free a stranded tanker by pumping cargo overboard to lighten the ship. The principal trade-off is to save the ship and the bulk of the cargo from complete loss at the expense of a certain amount of spill pollution. Pumping by ship systems is implied.

System Description

The key elements of the system are:

1. Ship's pumps - must be operational
2. Tow vessel to control the ship after it is freed

Pumps: The key to successful jettisoning are operable ship's pumps. A typical 100,000 dwt tanker has 2-4 pumps and a total pumping capacity between 8,000 - 10,000 tons/hr. A ship removing cargo at this rate can reduce its load by 10 percent in one hour. This rate is an order of magnitude greater than can be achieved with four portable off-loading systems (i.e. ADAPTS). If cargo is jettisoned too slowly the ship may have a chance to become more severely stranded during the operation and the goal will not be achieved. Thus, portable pumping systems should not be considered for this purpose.

Tug: A tug or other tow boat is needed to control the vessel once freed until the vessel can regain steerageway. Depending on the tanker size, one or more 4,000 to 8,000-hp tugs may be required. In the event the ship's steering has been damaged, the tug can tow the tanker to a port for repairs.

System Function

The key to successful freeing by high-rate jettisoning is the quick and decisive action on the part of the ship's crew and the Coast Guard response personnel who have the authority to permit the operation to proceed. Providing that the ship's pumps are operational, the jettisoning operation should begin by determining the optimum pumping sequence of tanks to retrim and lighten the ship. Structural considerations as well as the believed point of grounding are used to establish this sequence. A quick and accurate assessment of the ship and cargo condition is needed here.

Preferably, the weather should be favorable for jettisoning. That is, the wind should be blowing away from the coast line or environmentally sensitive areas so that the discharged oil will not be transported by the wind to these places.

When preparations are completed, the cargo pumping can begin. The tow vessel must be in place and ship's engines ready. The operation should be planned so that jettisoning is completed as the tide reaches its upper peak. The amount of cargo to be jettisoned should have been estimated based on the assumed grounding force. By weighing the tidal lift, available pulling power (ship's screws, or tug assist) and the required load reduction, a minimum of cargo can be jettisoned. Generally, the piping manifolds will exit at the side of the vessel and the oil can be jettisoned directly into the water. Even if the manifold is located elsewhere, given the circumstances, oil could be discharged onto the deck and would merely run off over the sides.

While it might seem wise to first jettison the oil from badly leaking tanks, this would not provide additional buoyancy and would increase the pollution. Such tanks are probably better left alone. The oil in them would probably only leak to a point

and then stop, at which time the oil remaining would still be contained even by the damaged tank.

Although not necessary for successful jettisoning, it would be preferable to have spill cleanup or mitigation equipment standing by to reduce the pollution effects. This, however, could require considerably more time before jettisoning could begin, which could increase the risks of not freeing the ship successfully. A typical jettisoning scenario might be envisioned as follows:

1. Grounding occurs and the Coast Guard (CG) is notified.

2. CG immediately takes command and dispatches assessment team by helicopter to tanker site.

3. Emergency tug and barge chartering provisions are enacted, and these vessels are dispatched to the site.

4. SWATH-type dedicated skimmers (Coast Guard) are ordered to proceed to the site. Transit at 20-30 knots begins. Dispersion systems and backup skimming systems are dispatched.

5. Vessel assessment indicates that jettisoning will be necessary to save the ship from breaking up and spilling the bulk of the cargo. The decision to jettison is made.

6. With a tug ready to assist, and at the best time (high tide, favorable wind direction, etc.) jettisoning begins. If possible, the jettisoning is delayed until skimming and dispersing systems are on site.

7. Ship is freed, and tug assists until the tanker is underway.

8. Skimming and dispersion is performed to clean up the oil.

Ratings

The ratings are presented in Table 6.

Performance: Performance compared to off-loading with portable pumps rates very high, because of the extremely high pumping rate. Heavy oils that have been heated during transport will not have had time to cool down significantly and should be easily

TABLE 6 . CARGO JETTISONING WITH SHIP'S PUMPS

Ratings vs. Scenarios		Sea State	Sea State 4				Sea State 6			
		Oil Viscosity	Medium Crude 30 cs		Heavy Oil 5000 cs		Medium Crude 30 cs		Heavy Oil 5000 cs	
Wt.	Factor	Vessel Type	Tanker	Barge	Tanker	Barge	Tanker	Barge	Tanker	Barge
0.30	Performance		.8	.8	.8	.8	.8	.8	.8	.8
0.15	Operational Control		.9	.9	.9	.9	.7	.7	.7	.7
0.15	Personnel		.9	.9	.9	.9	.8	.7	.8	.7
0.15	Mobilization & Setup		.9	.9	.9	.9	.9	.9	.9	.9
0.10	Support Logistics		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
0.05	Reliability		.9	.9	.9	.9	.8	.8	.8	.8
0.05	Long-Term Environmental Effects		.2	.2	.2	.2	.2	.2	.2	.2
0.05	Survivability		.7	.6	.7	.6	.6	.5	.6	.5
		Totals	.80	.79	.80	.79	.75	.73	.75	.73

pumpable at high rates. Because jettisoning would normally be attempted with all ship's systems intact, its potential for success in freeing the ship without further damage is higher than any other Regime 1 system in extreme weather.

Operational Control: The rating is high because jettisoning is accomplished simply by opening the correct valves and starting the pumps. However, the towing assistance in heavy weather would not be without control problems.

Personnel: Operating the ship's pumps is a regular function and not demanding of personnel. However, making hookups to the support tug may involve some personnel difficulties. Oil spillage on the tanker deck would present some hazardous conditions for deck personnel.

Mobilization and Setup: The only mobilization required is to get the standby tow vessel on site. Setup problems for towing could present some difficulties, depending on the orientation of the ship, etc.

Support Logistics: No support logistics are required.

Reliability: The pumping system aboard the ship has been designed to be reliable and should not be a limiting factor. The tow vessel may have more difficulty holding the vessel stationary during jettisoning in higher sea states, slightly reducing the reliability rating.

Long-Term Environmental Effects: Jettisoning could produce more long-term environmental effects than any other successfully accomplished Regime 1 response method (except possibly burning), because of the massive spillage that could result. However, these effects are more a function of the steps taken to mitigate the spill rather than the jettisoning itself. The ultimate effects would be far less than if the ship were left to break apart, spilling all of its contents.

Survivability: This is a function of the ship's structural integrity and grounding status. While more vulnerable than usual, if the pump room remains intact and power is available, the system

should survive. An increase in sea state increases the chance of engine and pump room flooding and lowers the survivability. The smaller barge case is also rated somewhat lower than the tanker due to the larger effect of heavy seas on it.

Time Considerations

Potentially, this system has the fastest response of any Regime 1 system. Even without the benefits of a standby tug, thorough cargo and ship assessment, and optimum environmental conditions, the operation may be successful in freeing the ship without further incident. The unknown factor in planning the operation is the length of time that the ship can afford to wait for optimum conditions (tugs, tides, etc.) before further damage occurs. The worse the weather, the less this time period is likely to be. On the other hand, the worse the weather, the more important it is to have a tug available. The time "window" for successful jettisoning, therefore, shrinks with worsening weather.

Coast Guard Impacts

The biggest problem with jettisoning may be in promoting the concept and overcoming the administrative, legal, and political objections of the method as a planned response technique for extreme weather. As far as equipment impacts are concerned, two areas are of primary concern:

1. Standby tug or assistance vessel (210-foot WMEC cutters may be helpful, but large offshore tug/supply boats would be most desirable)

2. Cleanup provisions to handle the jettisoned cargo.

Suitable tugs can probably be obtained through the MSO's. Quick response is needed, because jettisoning must be done early to ensure a high probability of success. The cleanup problem, which is discussed elsewhere, could be the key to acceptance of the jettisoning concept; if rapid and thorough cleanup could be accomplished with some degree of assurance, then jettisoning would be easier to accept.

Related Development Areas

Rapid cargo and ship assessment techniques

Oil spill cleanup methods for extreme weather

4.2 Vessel Ballasting Systems

System Objective

To stabilize a stranded vessel for later off-loading and salvage operations. This system would be for emergency deployment where ship's systems may be inoperative. The objective is to buy time, by stabilizing the vessel sufficiently to wait out heavy weather without further damage to the vessel.

System Description

The key elements of the system are:

1. Emergency mooring provisions, to prevent turning on the strand or broaching.

2. Cargo and ship assessment methods that can be rapidly utilized.

3. Pumping systems for flooding ullage spaces and other void spaces on the vessel with seawater.

4. Delivery subsystems.

Although flooding down to stabilize a ship is not a new technique, the provision to do it rapidly with other than the normal ship's systems is uncommon. Existing Coast Guard pumping systems, including ADAPTS, could be utilized for this service, but system modifications or new systems could probably be developed to make flooding more effective.

Emergency mooring provisions: Because the grounding will usually occur with the forward portions of the vessel carrying the reaction force, the ship's anchors will not be usable unless they can be shifted to the stern. A possible mooring system would utilize externally-supplied anchors that could be supplied by Sky-crane helicopter or by a vessel, such as the Coast Guard sled. Because winches would probably not be available, the mooring would have to be attached to a hard point on the ship and then the anchor set out to hold the desired position.

Cargo and ship assessment methods: Rapid assessment of the cargo, ship and bottom conditions must be made to determine whether ballasting is feasible, and into which tanks ballast water should be pumped.

Pumping systems: The ideal pumps are low head, high volume, low weight centrifugal pumps that can be handled like ADAPTS and powered with the ADAPTS power unit. The ADAPTS pump itself would be useful, and could accomplish about 350 tons per hour ballasting. Another approach is to utilize a high-volume portable (skid-mounted) well-point pump, or an auxiliary support-vessel pumping system (fire system, etc.).

Delivery subsystems: Helicopter delivery (Skycrane) is feasible, as long as clear area is available for setting down the cargo.

System Function

Determination of the best place to pump in the water is the key to the operation. Setup and operation of the equipment should present no unusual problems, although larger systems will be more difficult to maneuver around than smaller ones. Suspending the pump over the side using a tripod will require extra rigging to secure the tripod, and any wave action may cause some banging of the pump against the side of the ship.

Cargos with high specific gravity should have more ullage space available for ballasting. Most of the available extra space could be concentrated in a few tanks, such as ballast tanks, or unusual cargo spaces. Double bottoms, inoperative engine rooms, and other spaces could also be flooded.

Ratings

Ratings are presented in Table 7.

Performance: With denser cargos, more cargo space may be available for ballasting, and therefore more stability can be put into the vessel. Higher sea states will create more forces on the

TABLE 7 . VESSEL BALLASTING SYSTEMS

Ratings vs. Scenarios		Sea State	Sea State 4				Sea State 6			
		Oil Viscosity	Medium Crude 30 cs		Heavy Oil 5000 cs		Medium Crude 30 cs		Heavy Oil 5000 cs	
Wt.	Factor	Vessel Type	Tanker	Barge	Tanker	Barge	Tanker	Barge	Tanker	Barge
0.30	Performance		.7	.8	.8	.9	.4	.5	.5	.6
0.15	Operational Control		.9	.8	.9	.8	.6	.5	.6	.5
0.15	Personnel		.8	.8	.8	.8	.6	.3	.6	.3
0.15	Mobilization & Setup		.8	.9	.8	.9	.7	.8	.7	.8
0.10	Support Logistics		1.0	1.0	1.0	1.0	.9	.9	.9	.9
0.05	Reliability		.8	.8	.8	.8	.7	.7	.7	.7
0.05	Long Term Environmental Effects		.7	.8	.8	.9	.6	.7	.7	.8
0.05	Survivability		.8	.7	.8	.7	.8	.5	.8	.5
		Totals	.79	.83	.83	.86	.58	.54	.62	.58

vessel, and will decrease the likelihood of success. A barge can be stabilized faster because of its smaller size, but this smaller size also means that less mass is present, and therefore the barge may be more subject to working and shifting in higher waves. The net result may be a slightly higher rating for the barge.

Operational Control: This is a relatively simple, straightforward procedure and operations should present no unusual problems as long as room to set up is available, and deck angles, motions, and washover are not severe. However, as ballasting continues, freeboard could become low enough so that deck washover could be a problem. Ratings were made lower for higher sea states, especially for barges, where washover is more likely.

Personnel: Personnel will not be subjected to any more stress than in an off-loading case, and with no lightering vessels involved, the general situation will be even better. As in lightering, working on a larger vessel will require more exposure time to the elements, but the conditions may be more stable. With high pumping rates, exposure times will be relatively short.

Mobilization and Setup: These problems are similar to the off-loading case, but simpler, as no transfer hoses or receiving vessels are involved.

Supply Logistics: Logistics problems are minor (fuel and supplies), although supply of these items in the higher sea state may be more difficult.

Reliability: Reliability would be high because individual components would probably be fairly well developed. Sea state should have little effect, except possibly on mooring systems.

Long-term Effects: There are no direct environmental effects. The problem is that this approach does not solve the ultimate problem of getting rid of the pollution threat. In fact, it stretches out the operations to remove the ship from the strand, because of having to pump off the ballast water. However, water is easy to transfer, and stabilizes the ship while off-loading is taking place. Because a barge is smaller, any potential effects will be less than the tanker case.

Survival: Survival should not be a severe problem, and pumping operations on a stable vessel can be carried on more successfully than most other response operations. Survival on a barge in sea state 6 is less likely, however.

Time Consideratons

For ballasting, the critical time stages are in the initial situation assessment and in rigging the pumps for ballasting. If pumping systems are mounted on auxiliary vessels and water must be pumped to the casualty, the mooring and control problems will be similar to the off-loading case. An example time-line diagram for this approach is given in Appendix D.

Coast Guard Impacts

For ballasting there are available air-transportable, skid-mounted, diesel-driven well-point pumps with capacities exceeding 6,000 gpm and heads of 80 feet. Development efforts would be in the minor to limited category, and the development expenditure would be small. Production systems could be expected to cost in the order of $30K to $50K, depending on the appurtenances and modifications required. Large, lightweight hoses, (10-inch or larger) or piping would be required to complete the system.

Certain submersible pump designs similar to the ADAPTS concept have capacities in the order of 2,000 gpm. Possibly no development program would be required, as some of these systems are already well developed for shipboard use.

Other ship stabilizing techniques would require more development, such as mooring systems that could be quickly transported to the casualty site and deployed. In any case, a minor to limited development effort may be required to define the general techniques required to deploy the mooring systems in a variety of situations. Development expenditures would probably be small.

Rapid assessment of the ship and cargo condition is essential to the stabilization techniques as well as off-loading, etc.

In general, more investigation of ballasting and stabilizing as an initial response technique should be performed. Characteristics of typical tankers and barges should be studied in more

detail, potential ballasting spaces should be identified, potential ground reactions predicted, and techniques of flooding these spaces should be assessed. A small development expenditure would be involved in a study of this type.

Related Development Areas

Rapid ship and cargo assessment methods

Floating breakwaters to smooth seas

4.3 Cargo Off-loading to Receiving Vessels or Continuous Flaring, using Portable Pumps

System Objective

To control the vessel and begin cargo off-loading when necessary, with the objective of refloating the vessel with a minimum of further damage or pollution. For holed tanks, the objective is to minimize further pollution by removing the oil in a controlled manner.

System Description

The following components and subsystems are assumed for the system:

Pumps: Submersible pumps are required that can be lowered through available deck openings, and are capable of emptying a tank. This implies that the pump must fit through the Butterworth opening of a large tanker, because typically on such vessels there is a staircase below the manway, leaving the Butterworth fittings as the only openings where a pump can be lowered clear to the bottom.

Deep-well pump designs, such as ADAPTS, will fit through Butterworth fittings, and have capacities for crude oil (30 cs) in the order of 1,000 to 1,500 gpm, depending on pumping resistance and elevation. Capacities for 5,000-cs oil are an order of magnitude less, typically 150-300 gpm for most configurations, therefore requiring long pumping times if supplemental oil heating is not available.

Power Systems: These are self-contained systems typically employing a diesel engine designed for hazardous locations, hydraulic supply pump and associated controls, reservoirs, etc. These units can be handled in most cases by four men or less, using block and tackle, and can be located anywhere within the limits of the hydraulic hose lengths, where deck wash-over is not likely.

Handling Systems: For the pump, a tripod is used, with block and tackle for lowering the pump unit into the tank. Movements around

the deck can be done by hand with most pumps, or by block and tackle for the heavier systems. To load the components onto the deck, an HH-3 or larger helicopter should be used.

Hoses: Transfer hoses larger than the lightweight 6-inch ADAPTS-type hose are difficult to maneuver on deck when full of oil (10 feet of full 6-inch hose weighs approximately 140 lbs.). Hoses should be connected to larger deck piping if convenient, in order to reduce pressure drop over long transfer lengths. With a lightering vessel positioned approximately 100 feet off the tanker, a hose length of approximately 200 feet will be required to reach the lighter and allow for surges. The 6-inch ADAPTS-type hose can be utilized (with floats), but several hoses would be required to minimize pressure drop (and maximize flow), especially with viscous oil. Preferably, larger diameter, heavy-duty floating oil transfer hoses would be utilized, as discussed later.

Oil Receiving Systems:

Lightering: The state-of-the-art approach to oil removal is to pump it into a lightering barge or tankship. However, certain flaring systems are also state-of-the-art, and continuous oil burning can also be considered. A lightering vessel should be as large as possible, consistent with availability, so that interruptions due to vessel switching are minimized. To provide a relatively stable working platform for handling hoses and rigging, a barge or small tank-ship is required. To off-load relatively small amounts of cargo out of leaking tanks, a large, rubber-bladder type of oil container can be used.

Fendering a shallow draft receiving vessel alongside a stranded tanker in heavy weather could not be done easily, and other methods for securing the receiver would be desirable. Anchoring the vessel nearby could also be difficult. One possible method is to moor the vessel to two points on the tanker, and then hold it away from the tanker with a tug, as discussed later.

Flaring: The technology of oil burning is well-developed, being essentially the same as that of burners used in oil-well testing. These systems consist of a burning nozzle mounted on the end

of a boom extending about 60 feet out from the side of a vessel or oil rig. Air and water are provided for combustion, heat shielding, and smoke reduction. Gas pilot lights are included to maintain combustion. Where heavy oil is to be burned, dilution with light oil or preheating of the oil must be included. Systems are available that will burn oil with up to a 50-percent water content.

Commercial oil burners for use on ships are available with capacities to 12,000 bbl/day (350 gpm). Three such units would be required to burn the 1,000-gpm oil flow from a single ADAPTS pumping system. Auxiliary systems to support this burning rate are considerable, including approximately 720 hp for atomizing air, water injection, and primary air, and 95,000 SCFD of fuel gas. Three assembled flaring systems would weigh on the order of 45,000 pounds, and would require a separate vessel to support and transport them.

System Operation

The off-loading concept can be used in three different modes:

1. Remove cargo from leaking tanks to prevent further pollution. Cargo can be pumped to sound tanks or to a receiving vessel alongside. Delivery of the lightering vessel could be the limiting subsystem for off-loading. Delivery of a rubber bladder by sled or helicopter (Skycrane) would be fastest, but a vessel must be standing by to assist in rigging the bladder.

2. Remove cargo with the intent of lightering the ship for pulling off the strand. Cargo is pumped to a large receiving vessel or flaring system. The ship must have tugs or moorings to control her when she frees. Because oil pumping and/or flaring can be relatively slow, this process could take considerable time, and it exposes the ship to rough conditions which could jeopardize the salvage operations.

3. Remove cargo while replacing it with an equal volume of water, in preparation for a rapid freeing operation. This is the preferred method of freeing a tanker, and it assumes that the tanker has been made hard aground with ballast to keep her stable until the critical freeing operation takes place. At that time, high-volume

salvage pumps transfer the ballast water overboard, causing a rapid lightening at the optimum time (high tide, favorable current, etc.).

The selection of the tank pumping sequence requires careful consideration, although pumping of leaking tanks would normally rate first priority. Critical elements are then the assessment time, the time for an adequate size tug or salvage vessel to secure the tanker, and the delivery and stationing of a suitable receiving vessel or flaring vessel.

Ratings

Ratings are presented in Tables 8 and 9 for off-loading into receivers and for off-loading to state-of-the-art flaring systems, respectively.

Performance: A given number of pumping systems will have more effect on a barge than on a much larger tanker due to the quantity of oil that must be off-loaded to remove the vessel from the strand. Light oils will be much easier to pump than more viscous ones, if the heavy oil can be pumped at all. The performance of the pumps will not be directly influenced by the sea state.

Using state-of-the-art flaring systems, the disposal rate for oil would probably be limited to around 1,000 gpm in order to limit the number of burners and to keep the energy release to a controlled level. This rate may be suitable for a barge case, but would be small for a large tanker off-loading situation.

Operational Control: A pumping operation is under good control at all points, because the pumps can be shut down on short notice, and the pumping rate can be watched. Higher sea states will diminish control because of the difficulties of performing tasks on the deck of either a tanker or a receiving barge. Operation on a barge is rated lower in higher sea states because of the likelihood of the decks being awash.

Operational control for a small flaring rate may be fairly sound. A shifting wind could cause serious difficulties--both in handling hoses and in regards to the hazard from burner flames. The energy released from 1,000 gpm of burning fuel is enormous, and

TABLE 8 . CARGO OFF-LOADING INTO BARGES OR OTHER RECEIVERS

Ratings vs. Scenarios		Sea State	Sea State 4				Sea State 6			
		Oil Viscosity	Medium Crude 30 cs		Heavy Oil 5000 cs		Medium Crude 30 cs		Heavy Oil 5000 cs	
Wt.	Factor	Vessel Type	Tanker	Barge	Tanker	Barge	Tanker	Barge	Tanker	Barge
0.30	Performance		.8	.95	.4	.6	.8	.95	.4	.6
0.15	Operational Control		.7	.7	.7	.7	.6	0	.6	0
0.15	Personnel		.7	.5	.7	.5	.6	.1	.6	.1
0.15	Mobilization & Setup		.5	.5	.5	.5	.4	.1	.4	.1
0.10	Support Logistics		.3	.6	.3	.6	.15	.3	.15	.3
0.05	Reliability		.7	.7	.6	.6	.5	.1	.4	.05
0.05	Long Term Environmental Effects		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
0.05	Survivability		.6	.4	.6	.4	.5	.1	.5	.1
		Totals	.64	.68	.52	.59	.54	0	.43	.0[illegible]

TABLE 9 . CARGO OFF-LOADING TO STATE-OF-THE-ART FLARING SYSTEMS

Ratings vs. Scenarios		Sea State	Sea State 4				Sea State 6			
		Oil Viscosity	Medium Crude 30 cs		Heavy Oil 5000 cs		Medium Crude 30 cs		Heavy Oil 5000 cs	
Wt.	Factor	Vessel Type	Tanker	Barge	Tanker	Barge	Tanker	Barge	Tanker	Barge
0.30	Performance		.5	.7	.5	.7	.5	.7	.5	.7
0.15	Operational Control		.5	.7	.5	.7	0	0	0	0
0.15	Personnel		.5	.6	.5	.6	.1	.1	.1	.2
0.15	Mobilization & Setup		.4	.5	.4	.5	.2	.2	.2	.2
0.10	Support Logistics		.8	.9	.8	.9	.5	.6	.5	.6
0.05	Reliability		.5	.5	.5	.5	.3	.3	.3	.3
0.05	Long Term Environmental Effects		.9	.9	.8	.8	.9	.9	.8	.8
0.05	Survivability		.3	.3	.3	.3	.1	.1	.1	.1
		Totals	.51	.64	.51	.64	0	0	0	0

the flames from the burners are very large, hot and violent. In sea state 6 this approach is considered infeasible with state-of-the-art systems.

Personnel: This area is given a lower rating for the barge casualty case and higher seas due to the hazards and difficulties of working on the deck. The rating drops sharply for the barge in sea state 6 because of the probability of the decks being awash.

Due to the hazardous nature of oil burning, it has been assumed that a high level of personnel effectiveness is required if state-of-the-art flaring systems are used. Ship motion, icy conditions, and cold wind will reduce personnel coordination and alertness, so that a relatively low rating must be given to this factor, decreasing with worsening sea conditions.

Mobilization and Set-up: This includes getting both the pumping systems and the first lightering vessel (or flaring vessel) to the scene, which can be more difficult with a smaller casualty vessel and in higher sea states.

Deployment of a state-of-the-art flaring system, which must be permanently installed on the support vessel (due to boom installation requirements and the large quantity of power and fuel needed), will be slow and difficult. There is no way to effectively air-deploy the system, and the large, stable platform required will have a low speed of transport.

Support Logistics: This may involve the supply of several vessels to receive off-loaded oil. Larger casualty vessels will generally require more lightering vessels. Higher sea states will increase the mooring difficulties and lengthen turn-around time.

With state-of-the-art flaring systems, only fuel and auxiliary fuel gas are needed for support, as well as personnel needs. The lack of support logistics problems is the highlight of this approach.

Reliability: This may be somewhat affected by increased viscosity of the oil, which loads up the pumps and power units, and also by sea state, which could cause power units to be flooded and hoses broken.

Long-term Environmental Effects: While the burning nozzle systems are designed to produce low levels of smoke and atmospheric contamination, it is anticipated that there will be some degree of contamination resulting from their operation, especially with heavier, more viscous oils. For off-loading into receivers, there are no appreciable long-term effects.

Survivability: Higher sea states and small casualty vessels (barge) will reduce the survival potential.

Time Considerations

For off-loading, the critical stages appear to be in mobilizing the barges or tankships, and mooring them off the casualty. The pumping time is a strong function of the number of pumping systems utilized and the cargo viscosity, which must be kept low by heating, if necessary, in order to achieve reasonable pumping rates with ADAPTS-type pumps. In general, off-loading is a slow process compared to jettisoning, and off-loading to state-of-the-art flaring systems can be even slower, because of the limited rate that can be burned safely. An example time-line diagram for this approach is shown in Appendix D.

Coast Guard Impacts

The existing ADAPTS off-loading concept is adequate for organized salvage operations and for emergency pumping of breached tanks. Although lighter-weight pumps, high capacitites, and other minor system improvements would be desirable from an operating standpoint, no major impacts are foreseen for pumping system development. However, the problems of handling the recovered oil in heavy weather must be dealt with, as discussed later. The siting studies performed by Transportation Systems Center (TSC) should be adequate for the extreme weather situation.

Conventional high-capacity off-shore burners cost on the order of $80K per system. In addition, water pumps and, in most cases, air compressors are required, as well as supplies of igniter gas and electricity. For recovered oil burning, auxiliary oil pumps may also be required to provide the optimum pressure to the burner head. Development work would be required to establish the best configurations and system designs for use by the Coast Guard. Because

existing systems are fairly well developed, a limited development effort would be anticipated, with a small to medium development expenditure involved. Development of a self-contained, multiple-burner, barge-mounted system could be accomplished through several approaches such as:

1. Constructing a multi-purpose barge-burner system from ground up. A low-response hull design could be used. Effort would be incremental to the barge systems discussed under Oil Storage.

2. Adapting an existing barge.

3. Contracting for a barge, upon which several portable burner systems can be mounted.

Although state-of-the-art flaring systems are slow for tanker off-loading, they may be adequate for oil skimming systems, where the recovery rates are inherently slower.

Related Development Areas

1. Booster pump systems for utilizing higher-pressure floating hoses.

2. Floating transfer hose systems.

3. Mooring systems for lightering vessels or conventional vessels equipped with flaring systems.

4. Low-response floating platforms for supporting off-loading or flaring operations.

5. Improved flaring systems.

6. Floating breakwaters to smooth the seas in the off-loading vicinity.

7. Cargo heating systems for viscosity reduction.

8. Insuring the availability of receiving vessels.

4.4 In-Situ Burning of Cargo through Bombing and Shelling

System Objective

To burn the tanker cargo while it is still contained in the tankship through the use of bombs. Historically, considered when other approaches have failed.

System Description

In concept, the system consists of bombs to open up the tops of tanks and provide an ignition source for initiation of cargo burning. The bombs are normally dropped by aircraft but could also be launched from shore as rockets. The bombs can be two-part devices: the initial impact to open the hull plating (roughly 1-¼" thick), with a time delay to cause the explosion to occur after the bombs have broken through the deck.

After sufficient oil has burned off to lower the tank level, vent holes can be opened in the tank sides, perhaps with gunfire. Tests conducted by the Rocket Propulsion Establishment[6] in England after the Torrey Canyon have shown that a top opening and a side vent opening of approximately 10 percent of the oil surface area are required for maximum combustion of the oil.

Wind speed affects the burning with the burning rate in an 11 meter/second wind being approximately two to three times the rate in still air. Typical burning rates for a large tank are given below (for 10-percent side and top venting):

Wind Speed m/sec	0	6	11
Burning Rate, mm/hr	80	190	265

At this point, it is not possible to estimate the exact size or quantity of bombs to open up and ignite a 100,000 DWT tanker. However, based on the vessel having 3 transverse tanks and 5 longitudinal tanks, it can be assumed that at least 15 bombs would be required.

Limitations on bombing as a response technique are not only due to the vent area requirements, but involve a number of other

factors as well. Accuracy of bombs for this purpose and repeatibility to precisely open up a tank in a given way are not well known. Accuracy will be dependent upon visibility which may be low after the initial hits, since considerable smoke will be present. The method is not easily controllable; one could envision the possibility of enough cargo burning for the tanker to be lifted free from the grounding at high tide, but extinguishing the fire could be impossible at that time.

There is no current method of easily monitoring the effectiveness of the burning. A means of knowing tank levels would be desirable during a burning operation to make operational decisions concerning opening up more vent areas, completeness of burning, knowledge of the ground reaction force, etc.

System Function

The system operates as described above. Bombs provide a vent area and an ignition source for burning. Oxygen for burning is supplied by air which enters through the side vents, once the oil level has dropped sufficiently for the vents to be opened up. Other functional features are described above.

Ratings

Ratings are presented in Table 10.

Performance: The oil must be burned down or off-loaded before vents can be opened in the side. It will be difficult to vent the center tanks, since they are inaccessible from either side. Bombs, rockets, and artillery shells seem to be a slow and tedious method to open large holes because they will generally open a hole of a not much larger diameter than the projectile itself. Projectiles have an advantage in that they do not require putting anyone on board the stricken vessel. Once the burn is started, there is no turning back to other courses of action. If conditions change, the chances for pulling the ship off or continued off-loading will have to be abandoned. The burning rate will be a function of the oil type; a 5,000-cs oil is considered unburnable by this approach.

TABLE 10. IN-SITU BURNING OF CARGO THROUGH BOMBING AND SHELLING

Ratings vs. Scenarios		Sea State	Sea State 4				Sea State 6			
		Oil Viscosity	Medium Crude 30 cs		Heavy Oil 5000 cs		Medium Crude 30 cs		Heavy Oil 5000 cs	
Wt.	Factor	Vessel Type	750 x 120 15 Tanks Tanker	430 x 80 30 Tanks Barge	Tanker	Barge	Tanker	Barge	Tanker	Barge
0.30	Performance		.2	.05	0	0	.2	.05	0	0
0.15	Operational Control		.1	.1			.1	.1		
0.15	Personnel		1.0	1.0			1.0	1.0		
0.15	Mobilization & Setup		1.0	1.0			1.0	1.0		
0.10	Support Logistics		1.0	1.0			1.0	1.0		
0.05	Reliability		.2	.2			.2	.2		
0.05	Long Term Environmental Effects		.4	.4			.4	.4		
0.05	Survivability		1.0	1.0			1.0	1.0		
		Totals	.39	.25	0	0	.39	.25	0	0

Operational Control: Control of the venting procedure depends upon the fire control of the arms which may be visibility dependent. The burning itself is uncontrolled but most likely confined to the ship. Stopping the burning would be virtually impossible once it was started. Sea state is not an important factor here.

Personnel: The personnel risk is very low as no one is required on the stricken vessel at any time before the burning. The venting would be done safely from aircraft and ships, presenting small risk to personnel.

Mobilization and set-up: Set-up required for this system consists of establishing liaison with the appropriate armed forces, and arranging for the required ordnance.

Support Logistics: The supply of explosives and projectiles can probably be carried out by state-of-the-art systems. However, Air Force or Navy aircraft would probably be required for launching. The technique is relatively insensitive to weather or sea state (except fog, etc.). For side opening, ships could be utilized, which are subject to sea state effects.

Reliability: It has not been proven that this method can create a sufficient vent area in the side of the ship. The burning may not sustain itself without additional fuel and may not burn a sufficient percentage of the cargo before it goes out for lack of oxygen. The chance of further pollution by oil on the water is also high.

Long-Term Environmental Effects: Even a successful burn will result in air pollution, which is probably more acceptable than the oil-on-water pollution. If the vessel was close to shore, both the air pollution and the fire hazard would have to be considered. The possibility that water pollution may be caused by inadvertent tank opening is a factor, also.

Survivability: This is not considered a serious problem.

Time Considerations

Time is not a great consideration, because this method would probably be used only after other methods have failed.

Coast Guard Impacts

Bombing is outside the realm of Coast Guard capabilities, but well within the capabilities of the Navy or Air Force. Within these commands, ordnance types ranging from conventional bombs to advanced TV-guided air-surface missiles are available. However, such devices would probably not be suitable for the desired purposes without modifications or further development. Guidance could involve having devices planted on the deck to improve accuracy. Available missiles are very expensive, and possibly cheaper, more specific missile systems could be developed for tanker bombing applications. However, an advanced or possibly a complete development program would be required with probably a large to major development expenditure. A substantial number of devices would have to be kept on hand, as maybe 15 to 50 would be required to handle a large tanker, depending on their capabilities.

For opening the sides, conventional gunfire can be provided by certain Coast Guard vessels (WHEC's have 5-inch guns), and by several classes of Navy ships. Many rounds would be required, and possibly specially designed rounds would have to be developed to make shelling more efficient.

4.5 In-Situ Burning of Cargo Using Planted Explosives

System Objective

To burn the tanker cargo while it is still contained in the ship by cutting the hull tanks into suitable combustion chambers through the use of explosive cutting techniques.

System Description:

Some of the aspects of in-situ burning of the ship's cargo are discussed under "Bombing," and the same venting requirements for effective burning must be met here.

The best approach would be to cut many small holes in the ship between the frames, leaving the frames intact. This would provide the needed ventilation without the more difficult cuts involved in making single large holes. If ignition does not follow from the cutting operation, separatly timed incendiary charges, or bombs could be used to initiate burning.

One way to cut numerous small holes with minimum set-up time on board the vessel would be to prefabricate some cutting arrays. The cutting charges could be arranged in a ladder configuration narrow enough to fit between the ship's frame, and about 10-15 feet long. This arrangement would then cut a row of connected one-foot square holes in the plate.

The entire ship would preferrably be rigged with explosives and detonated at one time, because when the tanks were blown open, burning might begin at once and prohibit visits to the ship to arrange additional explosives. However, if the oil level in the tanks were too high, the oil would spill out before it was burned. Alternatives to rigging and detonating the entire ship would be to completely burn out one tank before rigging and blowing the next tank, or rig and detonate the tank tops (deck) only and allow the fires to go out before rigging and detonating the sides. Again, it would be impossible to open side vents in the central tanks of the ship with this method.

Under optimum conditions, the burning rate would be around one-half foot per hour, with a moderate breeze blowing into the side vent.[6] Therefore, it would take at least a week to burn out a 100,000-dwt tanker in the best of conditions.

Ratings

Ratings are presented in Table 11.

Performance: The operation of the explosives depends mostly upon the ability to position and rig them on the ship, which may be an impossible task. The optimum burning rate will be achieved only on one side of the vessel, depending upon wind direction. Only two thirds of the cargo can be handled in this manner, then additional artillery will be needed to open the central tanks. Lightering or jettisoning may have to be done to get the oil level below the side vent. The time required to complete the burn is on the order of one or two weeks. These factors result in the low performance rating. A 5,000-cs oil is considered too viscous to burn using this technique.

Control: The initial venting of the tanker is a relatively controlled procedure compared to bombing, but the question remains whether adequate venting can be accomplished at all. The burning is uncontrolled once it begins. However, it will be confined to the ship and not likely to spread upon the slick surrounding the vessel, due to the cooling effect of the sea water. Stopping the burning once it is initiated would be extremely difficult.

Personnel: A low rating is given because of the dangers involved in trying to set explosives on the tanker in high sea states. A great deal of time will have to be spent on the open deck arranging charges on the deck and over the side.

Mobilization and Setup: A stockpile of explosives for cutting would have to be built and maintained at a centralized location. The charges can be arranged in the ladder shapes on frames and fitted with magnetic securing devices. To completely perforate a 100,000 dwt tanker, in order of 20,000 pounds of shaped-charge explosive would have to be transported to the vessel. Planning and set-up would require a long time, and would be made more difficult by rougher weather conditions.

TABLE 11. IN-SITU BURNING OF CARGO USING PLANTED EXPLOSIVES

Ratings vs. Scenarios		Sea State	Sea State 4				Sea State 6			
		Oil Viscosity	Medium Crude 30 cs		Heavy Oil 5000 cs		Medium Crude 30 cs		Heavy Oil 5000 cs	
Wt.	Factor	Vessel Type	Tanker	Barge	Tanker	Barge	Tanker	Barge	Tanker	Barge
0.30	Performance		.2	.2	0	0	.1	.05	0	0
0.15	Operational Control		.3	.4			.3	.4		
0.15	Personnel		.4	.2			.2	.1		
0.15	Mobilization & Setup		.2	.3			.1	.2		
0.10	Support Logistics		.5	.5			.3	.5		
0.05	Reliability		.4	.5			.3	.4		
0.05	Long Term Environmental Effects		.4	.4			.4	.4		
0.05	Survivability		.5	.5			.4	.4		
		Totals	.29	.29	0	0	.18	.16	0	0

Support Logistics: No continuing support is required once the explosion has occurred, unless efforts to maintain combustion are required. Such efforts could amount to major problems, however, if more explosives are required.

Reliability: The reliability of the venting procedure may be fairly low, because of the complex system that must be hooked together in order to detonate the whole array at once. The burning reliability itself is probably low, too. Also, the reliability of performing the job without the risk of further pollution must be rated low. High sea states lower the reliability rating because the wave action may sweep the charges from the side of the vessel.

Long-Term Environmental Effects: A successful burn naturally results in air pollution, which is probably more acceptable than the oil-on-water problem, but which could be undesirable if the casualty was close to shore.

Survivability: Rough seas would decrease the possibility that side-mounted explosive arrays would stay in place and remain connected together properly. Otherwise, survival problems are probably not too severe.

Time Considerations

As discussed under Mobilization and Setup, planning and setup would require considerable time (possibly weeks). This would tend to religate this approach to a last-resort method.

Coast Guard Impacts

Studies would have to be made of representative ships to determine the best patterns for designing the explosive charge modules. Shaped-charge modules would cost on the order of $1 to $2 per pound, including detonators, primer cord, attachment devices, etc.

Siting could be at a few central locations, and the explosives trucked or flown to the staging area. Transport to the ship would best be done by helicopter to avoid handling problems. At the main storage sites special bunkers would have to be provided. Construction requirements of such facilities are fairly standard. Remote locations,

with plenty of land surrounding the bunkers, are desirable for safety reasons.

Special training would have to be provided to certain personnel, but staff additions may not be needed. Possibly, arrangements with Army or Navy explosives specialists could be utilized to provide the specialized personnel requirements.

Related Development Areas

Standard designs of explosive arrays.

4.6 Cargo Gelling

A possible method for reducing or preventing the loss of oil from tanks in danger of rupture is through cargo gelling. A gelling ingredient is mixed with the oil in a tank to solidify it. Thus, tanks that suddenly become partially open to the sea will not spill their contents. Gelled cargo could later be removed by heating until reliquification occurs (54°C).

The system requires a supply of gelling agent, cargo mixing systems, a cargo heating system, and transport and handling equipment.

The oil must be gelled to a self-supporting shear strength of approximately 1.2 psi in order to prevent extrusion through all but very large holes. Gel-forming reagents must be used at about 3 to 10 percent of the oil weight to be effective. These quantities would be logistically overwhelming if the entire cargo was to be gelled. A main tank on a 100,000-dwt tanker might contain 7,700 tons of oil and could require as much as 770 tons of gelling agent.

To form the gelled mass, thorough mixing is required. The mixing energy required for the above example is equivalent to the output of one ADAPTS pumping unit. Heating the cargo to 15°C for 8 to 24 hours is also required to complete the reaction. The presence of water is undesirable; only 2 percent water will reduce the shear strength by about 50 percent. Holed tanks that are spilling oil and have allowed some water to enter them would therefore not be gellable.

The development of cargo gelling suffers from a variety of complications. Both the large volumes of gelling agent needed and the extensive handling, mixing and heating requirements, represent severe logistics problems. This, coupled with the questionable effectiveness of the system for use in large tanks, suggests that the concept does not warrant additional development effort.

4.7 Summary of Rating Results for Regime 1 Systems

The most technically attractive approach to responding to a stranding casualty in extreme weather is to jettison cargo, using the ship's high-volume pumps. The method is fast and involves no external equipment other than a standby tug or other large vessel to control the ship until she can make steerageway. The price to pay, however, is in the pollution that will result, especially if the grounding is hard and considerable oil must be discharged. On the other hand, the difficult conditions in which to attempt other techniques, and the chance of averting a far greater disaster if the tanker eventually breaks up, make the limited pollution trade-off worth considering in the extreme weather case. The key to this approach, as in any other, is a rapid and accurate assessment of the siatuion.

The next most attractive approach is to ballast down and stabilize the ship and wait for good weather before launching an organized salvage attempt. A limited amount of external equipment is required, and no receiving vessels are necessary. Although there is a possibility that ballasting may not be sufficient to stop the shifting and working against the bottom that is so damaging to tankers, the techniques may buy the time necessary to do the salvage job properly. Certainly, if ship's power is not available for jettisoning, ballasting down and stabilizing becomes the most attractive first approach in heavy weather. Flooding of cargo holds should be employed during subsequent off-loading attempts anyway, to keep the ship stable; contamination of the cargo is not an important consideration. In most cases, jettisoning or ballasting are the only viable options for a grounding in bad weather -- all of the other methods require mobilization of heavy equipment (barges, tankships, etc.) or else they involve a greater risk of more pollution.

Off-loading systems, using flares or receiving vessels, can ultimately be used to help remove a ship from a strand, but for a first response in bad weather, other methods are faster and simpler. Portable pumps, for lowering through Butterworth fittings, are relatively low in capacity, and are best utilized as part of an orderly salvage in calmer weather. The exception to this is where a tank is breached, and pumping the contents to another container is the only way to mitigate the pollution. If jettisoning or ballasting (stabilizing) is not possible, then off-loading is the only attractive method left for coping with the problem in bad weather, even though considerable time may be lost in mobilizing and mooring the receiving vessels, and in setting up hoses. The use of a flaring vessel to burn the oil, instead of transferring it to shore, is appealing, but with present burning systems, this method could be slow, and possibly hazardous because of the tremendous amount of heat generated.

On-site burning of the cargo by bombing and shelling or by planted explosives is best suited to last-resort situations, where little hope of saving the cargo exists and any burning would be better than none. As a rapid response technique, neither of these approaches is suitable. Bombing and shelling suffer from lack of control, and the use of planted explosives could be hazardous to those personnel having to install them in rough weather.

Cargo gelling does not appear feasible except possibly in isolated cases, and is not considered a viable technique for heavy weather repsonse.

Table 12 summarizes the ratings made for the various state-of-the-art response systems.

TABLE 12. SUMMARY OF RATINGS FOR REGIME 1 RESPONSE METHODS

Ratings vs. Scenarios — Sea State	Sea State 4				Sea State 6			
Oil Viscosity	Medium Crude 30 cs		Heavy Oil 5000 cs		Medium Crude 30 cs		Heavy Oil 5000 cs	
Vessel Type	Tanker	Barge	Tanker	Barge	Tanker	Barge	Tanker	Barge
Cargo off-loading into barges or other receivers	.64	.68	.52	.59	.54	0	.43	0
Cargo off-loading to SOA flaring systems	.51	.64	.51	.64	0	0	0	0
Vessel ballasting systems	.79	.83	.83	.86	.58	.54	.62	.58
In-situ burning of the cargo through bombing & shelling	.39	.25	0	0	.39	.25	0	0
In-situ burning of the cargo using planted explosives	.29	.29	0	0	.18	.16	0	0
Cargo jettisoning using ship's pumps	.80	.79	.80	.79	.75	.73	.75	.73

4.8 Discussion of Gaps Pertaining to Regime 1 Response Systems

There are several technology gaps and problem areas that are specific to Regime 1, and have not been discussed in previous sections. These areas will be discussed in the following sections.

Assessment of a Stranded Tanker: When a tanker runs aground, prompt action is imperative to save the ship and prevent a major pollution incident. To determine the optimum action (i.e., jettison, ballast, off-load), it is necessary to quickly assess the vessel and cargo status. The draft, trim, and cargo volume of each tank must be determined along with other related conditions such as the weather, tide, and type of bottom.

Much of this information can be found by existing methods using state-of-the-art equipment, but this is often time consuming. Therefore, improvements in assessment techniques and their associated hardware would be desirable. Ideally, continuous output instruments would be used so that the response personnel could see at a glance the current status of the ship. In very few of these areas, however, is it practical to have continuous measurement devices. If measuring equipment can be designed to work with short sample times, frequent measurements will be possible.

Among the general assessment areas that require physical measurements are:

1. Oil and water levels, and rate of change. Such measurements are currently made with dip sticks, sampling, and electrical devices that sense a transition from oil to water or vice versa. A new device which would continuously measure and record the level of the oil-water interface (water level) and the oil level is desirable.

2. Oil viscosity and temperature. These can be readily determined using state-of-the-art portable assessment gear.

3. Ships draft, trim, and list. The ship's draft and trim are generally determined by observing the bow and stern draft scales painted on the hull. An improvement over this technique may be an electronic wave height gauge that could be used from the deck of the stranded vessel with an electronic averaging circuit to accurately determine the mean water level. The ship's angle of list and trim can easily be measured with a state-of-the-art bubble level device.

4. Bottom conditions. State-of-the-art equipment and methods provide this information. A bottom sample may be taken if this information is not specified by the chart, but the device for taking the sample must be made available.

5. Strain in ship's structural members. Presently, visual indicators of overloading are watched for (i.e., deck buckling or crack formation) but these may not appear until damage is imminent. One state-of-the-art method to observe the change in hog or sag of the ship is to observe the sag of a cable strung between uprights at the fore and aft ends of the vessel. Strain measurement can also be made by mounting portable mechanical strain gauges on the deck in high load areas. Little hardware development is necessary here, but rather the application of this technology to the particular problem is desirable.

After the many measurements had been made, the course of action would have to be decided. Sorting through the inputs and evaluating them could be a time consuming process. Often the actual status of the ship would have changed by the time the decisions were made.

To save valuable time on site and ensure preparedness, a written procedure for systematic assessment and response would be desirable. The final assessment plan must be flexible enough to suit a variety of situations.

It may also be feasible to utilize a shore-side computer to organize and draw conclusions from the data inputs. Such a computer would have to be preprogrammed for the necessary computations using specific data on the stranded ship characteristics, which would be drawn from a large data bank. Most of the calculations required in the decision process such as probable holing, ground reactions, etc., could be quickly and efficiently made by a computer. The result of the calculations would then enable the salvor to predict the results of several possible courses of action.

Improvements in assessment methods will probably involve a small to medium development expenditure, with much of the work directed towards developing the software and data base for quickly utilizing the results of the measurements provided by the on-scene personnel (strike team). Costs for any additional instruments should not be excessive. Additional personnel training may be required for taking data, but no additional strike team personnel would probably be required. Special training would probably be required for headquarters analysis personnel, and some additional staffing may be required to maintain the system (data bank).

Mooring Gear for the Stranded Vessel: One of the most important considerations in a stranding incident is to prevent further ship damage from movement on the strand. This, of course, is the main purpose of ballasting. However, in many cases ballasting may not be feasible. If large enough moorings can be placed at the proper points, the vessel may be restrained so that the wind and current changes do not move the vessel significantly.

Moorings cannot be placed by the stranded ship, although the bow anchors can be deployed by a separate ship. Additional anchors, cables, and floats must be brought to the scene by some vehicle that can also deploy them. For a surface vessel to pick up mooring gear and travel to the scene (the state-of-the-art

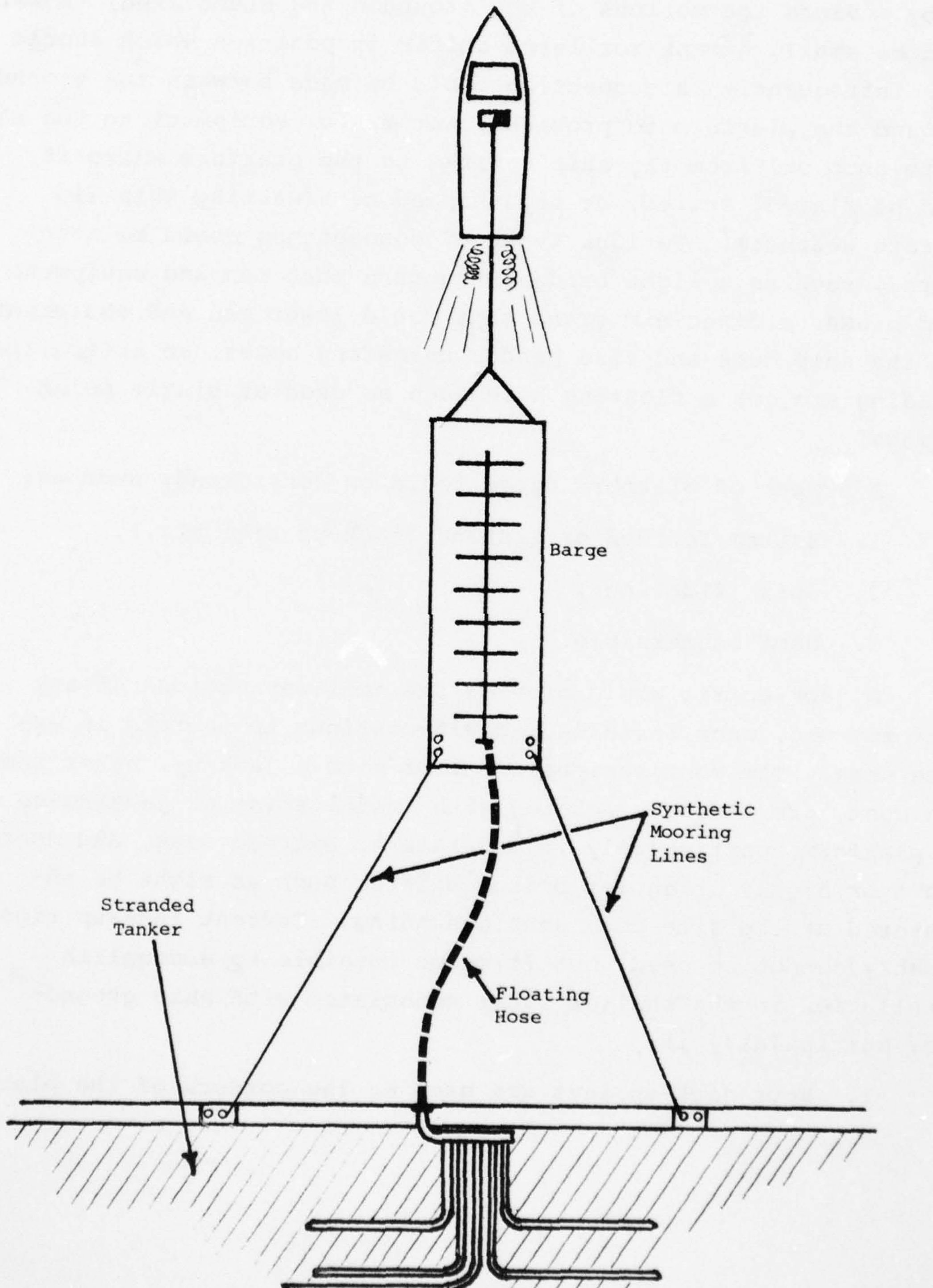
response method) may require one day or more. A helicopter-deployed mooring system appears worthy of consideration. As an example, a large helicopter (Skycrane) with a 20,000 lb. lift capacity and 250-mile range could possibly deliver and deploy a complete mooring leg (16,000 lbs.) consisting of an 8,000 lb. multipurpose mooring anchor, floats, chain and Kevlar cable for approximately 50 tons of holding force.

A helicopter deployable anchoring system could probably be developed in a minor development program, with a minor to small development expenditure. Larger capacity moorings would have to be ship deployed (a WLB would be a good vessel), but existing components could be utilized. Purchasing the components, plus a minor development effort to determine the best deployment techniques, are the main things required to develop a ship-deployed mooring system for stranded vessels.

Securing a Lightering Vessel to a Stranded Tanker for Off-Loading: Rough seas can make fendering a lightering vessel alongside a stranded vessel an unsafe operation. The sea conditions and short separation distance desired between vessels also makes anchoring somewhat impractical. A dynamic station-keeping system would be desirable but no typical lightering vessels have this capability and the shallow water in the vicinity of a stranded vessel could make this approach infeasible.

One system that is presently in use for securing off-shore supply boats to drilling rigs uses two synthetic mooring lines to tie the vessels together. Power is then applied by the supply boat to maintain tension in the lines. The synthetic ropes have significant stretch and act as springs to absorb the dynamic loads. The shock to the platform and vessel are significantly reduced and extreme weather transfer of cargo can be carried out. These systems are designed for 12-foot seas. Figure 2 shows how this system might be applied to an off-loading operation using a receiving barge and tug. Separations of 50-100 feet can probably be safely maintained.

FIGURE 2. PROPOSED MOORING FOR OFFLOADING STRANDED TANKER



Low-Response Support Platforms for Off-Loading: An effective means for removing oil from a grounded tanker would be through the transfer of oil to a relatively immobile platform stationed nearby. Since the motions of the grounded and stabilized) tanker would be small, except for large shifts in position which should occur infrequently, a connection could be made between the grounded ship and the platform to provide power and/or equipment to the ship, and to pump oil from the ship's tanks to the platform where it could be flared, stored, or transhipped to a waiting ship (in moderate weather). Various types of connections could be considered, such as a light bridge structure that men and equipment could cross, a fixed arm crane that could lower men and equipment onto the ship deck and also handle unloading hoses, an articulated unloading arm, or a floating hose such as used at single point moorings.

A number of platform types could be considered, such as:

1. Bottom founded or sitting (jack-up rig, etc.),
2. Spar (floating),
3. Semi-submersible.

A jack-up rig would provide the smallest motions of any platform, and, once installed, could continue to operate in extreme seas. The most serious problems with a jack-up, other than high cost, are those associated with installation or jacking-up of the platform, particularly in moderate to extreme seas, and where a soft or highly irregular bottom exists, such as might be encountered at the site of a ship grounding. Current jack-up rigs probably cannot be used, but it seems possible to accomplish installation in the shallow water associated with ship groundings, particularly if:

1. Four jack-up legs are used at the corners of the platform.

2. A constant tension-type support for the legs is used until the legs are lowered and seated on the ocean floor.

3. A dynamic positioning system is used to maintain position during installation.

Installation in rough seas could be simplified by prior deployment of a portable breakwater near the ship. One other problem is the possible need to reposition and reinstall the rig if a significant shift occurs in the position or orientation of the grounded ship.

The biggest problem with the deployment and use of a floating platform is the need for precise station-keeping and the need to reposition the platform if there is a significant shift in the position of the grounded ship. Station-keeping can be achieved either by the use of a multi-point mooring, which would be very difficult to set in any significant seas, or, through dynamic positioning, which is expensive and which requires the deployment of several sonar transponders. Dynamic positioning seems much more practical than mooring, however, although in shallow water difficulties may be encountered.

Spar platforms can be designed for very small motions over a range of wave conditions if sufficient draft can be provided. However, spars are not well suited to operation over the wide range of drafts required by groundings in relatively shallow water depths.

The semi-submersible has generally good sea-keeping behavior, even with moderate draft, and has moderate towing resistance or propulsion power. Semi-submersibles provide an excellent working platform and can be equipped with a number of connection devices. Semi-submersibles are probably better suited to dynamic positioning than a spar but the power required may be large. The biggest drawback to the semi-submersible is its high cost.

Because of the large size of the vessels considered, the impacts of a low response support platform would be similar in scope to the floating breakwaters discussed in the next section. Dedicated personnel would be required to man and operate the platforms, which could be permanently supporting many of the systems and concepts discussed in other parts of this report. Costs of a system would be high (on the order of $10M-$20M) and the system may not be able to serve in a multi-mission capability. A complete development effort would be required and probably a major development expenditure would be involved.

Floating Breakwater: Rough seas are the cause of many of the difficulties encountered during off-loading or salvage operations. One possible solution to this problem is the deployment of floating portable breakwaters or wave energy absorbers. The energy in a typical fully developed sea is maximum in the longest wave lengths and absorption of this energy could require very large systems; however, for securing access to a stranded vessel and operating equipment of various kinds it may be sufficient to absorb only the most troublesome, moderately short wave lengths allowing the "smoothed" swells to pass. Such a system might be deployed in the lee of a stricken tanker or over a short length to windward. Operations would then proceed in the sheltered zone as described in Figure 3 . The devices might take the form of moored rafts, Salter ducks[7] or, possibly, an array of tethered spheres[8]. The theoretical basis for the design of good and practical systems is still under development[9,10].

Portable breakwaters large enough to significantly improve extreme weather operations around a stranded tanker would be on the order of ship sizes themselves. The cost of a 200-foot long breakwater would be on the order of a hull cost for a similar sized vessel (15-20 foot draft, 40-foot beam), which could be in the range of $1.5M-$2.5M. Mooring systems would add extra costs to

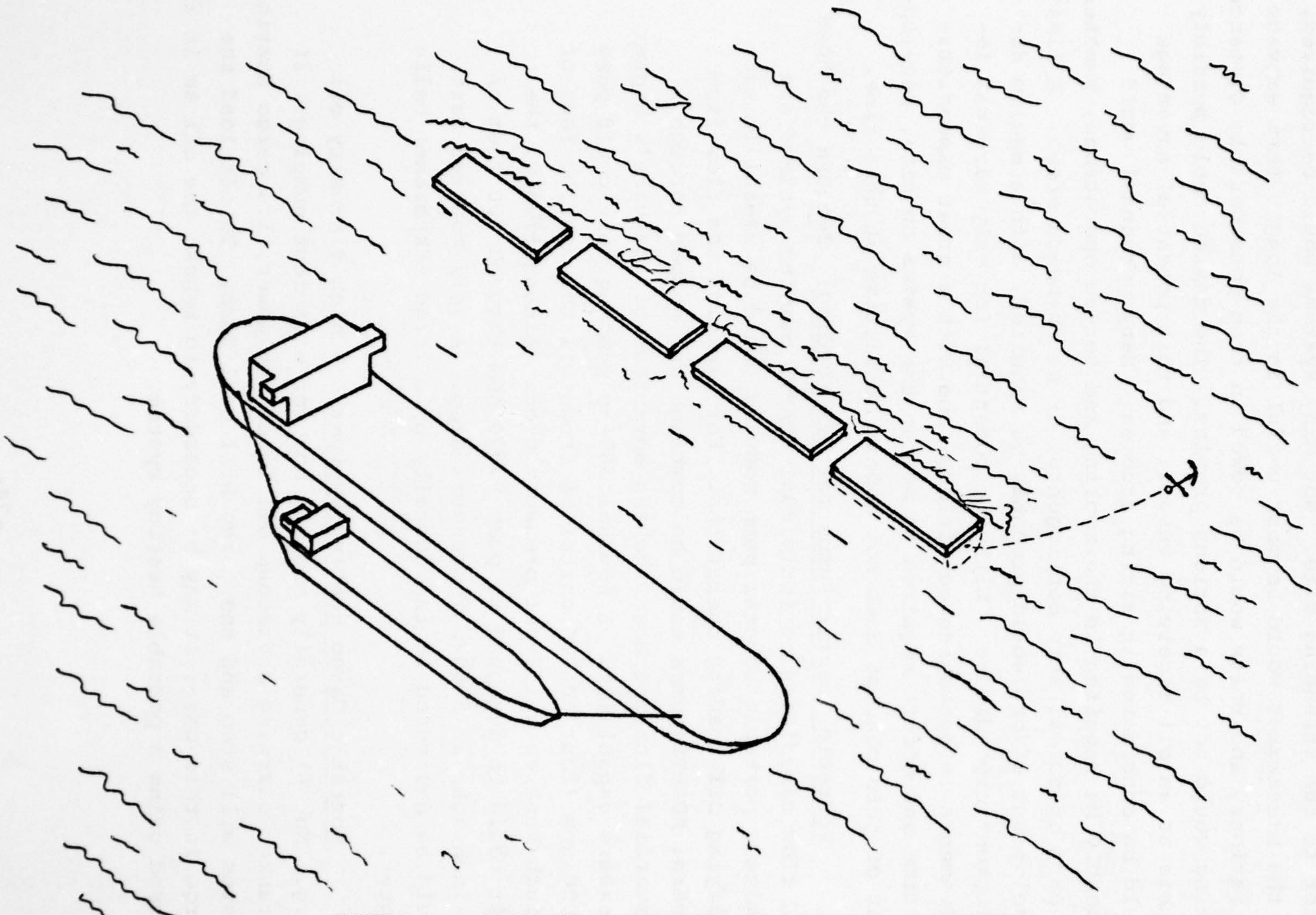


FIGURE 3. ARTIST'S CONCEPTION OF FLOATING BREAKWATER MOORED TO WINDWARD OF STRANDED TANKER

the system. Coast Guard vessels could probably tow the breakwater to the stranding site. Not many systems would be required, as the breakwater would be most useful in the longer-term salvage operations, and units would be towed in from considerable distances; siting would not be a serious problem. The device could possibly double as an oil receiving vessel, and this potential advantage could be considered in siting studies. Many personnel would probably be required in the mooring and set-up operations, whether as part of normal ship contingents, or as on-board crews. A limited development effort would probably be required, with a medium development expenditure. With the potential for only marginal improvements in operating conditions, and with a great expenditure of time and effort required to set up the system on site, development of this concept does not appear attractive at this time.

Portable Booster Pumps for Off-Loading: Because the head and flow capacities of individual ADAPTS pumping systems are limited, portable booster pump modules could be useful in simplifying off-loading operations. For example, the flow from several ADAPTS pumps could be combined and pumped through a commercial floating hose, taking advantage of the hose's higher pressure capability. A nominal 500-hp pumping unit could pump 4,000 gpm (four ADAPTS units) of crude oil through 300 feet of 6-inch hose at a 150-psi pressure drop. Alternatively, the unit could be designed to pump 9,000 gpm through 300 feet of 10-inch hose at a 60-psi pressure drop. A skid-mounted unit could be delivered to the casualty by a large (Skycrane) helicopter.

Portable Cargo Heating Systems: A high viscosity oil (e.g., No. 6) generally must be hot for efficient pumping. If a tanker carrying a viscous oil loses its power, its cargo heating system will stop and the cargo will cool down. To off-load the cargo in this case, it may be necessary to reheat the oil as it is pumped using a portable heating system.

Different methods of heating oil have been evaluated[11] including direct steam heating coils, direct electric heating coils, open-circuit steam heat, and hot-oil spray heating. Of these the oil spray shows the most promise for an extreme weather situation. Briefly, a hot-oil spray system for cargo heating would take a part of the pumped flow, add the desired amount of heat to it, and then return it to the cargo tank near the pump suction as a "spray" to mix with and heat the oil to be pumped.

The heat requirements can be considerable. For example, to heat 1,000 gpm of No. 6 fuel oil from $40^{o}F$ to $100^{o}F$ would require over 13-million Btu/hr. A typical off-the-shelf liquid phase heater for this heating rate would weigh in excess of 17,000 pounds. Clearly, the portability of the equipment must be a consideration in heavy weather, and delivering components of this size to the tanker deck may be impractical. Even a smaller 5-million Btu/hr. system could have components weighing in excess of 9,000 pounds (over 19,000 pounds total system weight), and could cost on the order of $75K-$125K per system.

The hot-oil spray heating system is only conceptual at this time, but it could be easily developed using conventional components. A limited development program would probably be involved, with a small to medium development expenditure to produce the first units. Alternative schemes should also be considered in any development efforts, as considerable weight savings and heat rate increases would probably be necessary to justify procuring highly portable systems for extreme weather use.

<u>Improved Salvage Capabilities</u>: The Coast Guard's role in the salvage phase of the operation can be direct, in which case a strong salvage capability should be developed; or indirect, where only support or advisory activities involving the pollution aspects are maintained. If a salvage capability were developed, then integration of large-scale pollution response approaches into

the overall salvage effort for tankers would probably be much more effective. At present, the absence of such an integrated pollution response/salvage capability represents a gap in the attainment of an effective extreme weather pollution response capability. Extreme weather operations, where the situation can quickly deteriorate, are the most important situations in which an integrated pollution response/salvage capability is necessary. Such a capability must include the authority to exercise best judgement without fear of retribution, the authority to rapidly mobilize whatever assets are necessary to effectively cope with all phases of the problem, and the mandate to take over the situation as soon as a casualty occurs. In this last regard, even the remote (not on-scene) authorization for a vessel to jettison cargo should be within the scope of the responsible agency's authority.

Attaining a strong salvage capability would involve a major impact on the Coast Guard. If a transfer of certain existing Navy salvage functions to the Coast Guard could be made, little change in total military assets would be involved. However, a transition period would be costly and it could take several years before the Coast Guard was fully operational with a new capability. In addition, major upgrading of salvage components and vessels would probably be required, especially to handle the larger tankers and freighters that are in service today, and to integrate the Coast Guard's pollution control functions in with the salvage capability. A major study would be required to fully assess the feasibility and impacts of transferring the Navy salvage function to the Coast Guard, or to evaluate attaining a partial or improved capability without a transfer.

5.0 REGIME 2

General Considerations

The objective of the responses in this regime is to minimize the environmental pollution resulting from an oil spill in extreme weather. The techniques to be considered are applicable to spills from tankers, oil well blowouts, pipeline ruptures, or other sources.

The problem can be divided into two response approaches. The first approach is to skim the oil from the surface and remove it from the environment altogether. This approach includes the various skimming and sorbent techniques. The second approach is to "redistribute" the oil throughout the environment. Included here are techniques such as dispersing, where the oil is broken into small droplets and distributed within the upper portions of the water column; sinking, where the oil is weighted down to cause it to sink to the bottom; and burning, where the bulk of the oil is converted to gaseous or airborne particulate matter and the rest (residue, burning agents) hopefully sinks to the bottom, or is skimmed off. An alternative approach, which, unfortunately, occurs more often than desired, is to allow all or a portion of the slick to seek its own fate. In these latter approaches, a desired result is to have natural oxidation and microbial action assimilate the oil into harmless waste products -- a tall order in a massive spill.

The usual objections to approaches where the oil is redistributed, is that the oil may exist in the environment for a considerable length of time, causing ecological damage to biota in the water column or on the bottom. Although rates of biological assimilation vary considerably in the open ocean, the upper limit may be on the order of 2-3 tons/square-mile/day near the surface, as determined by the availability of trace nutrients

such as nitrogen or phosphorous[12]. At this rate, even a dispersed 0.03-mm thick layer of oil would require on the order of a month to be assimilated. Because the long-term effects of oil on the biota are not thoroughly understood, it is safe to assume that, in general, removing the oil from the environment is preferable to redistributing it. However, skimming a large quantity of oil from the surface is difficult even under the best of conditions; the only alternative to incurring the damage that a free slick can inflict on the shoreline or near-shore areas may be to employ the "least undesirable" of the redistribution techniques. The employment of these techniques must be started early in order to confine the oil to the off-shore regions where the potential for ecological damage is the least.

The scenarios developed for comparing response methods depict several combinations of conditions that might be met in heavy weather situations. These scenarios are useful in comparing similar approaches (various skimmers, for example). However, when comparing skimmers with redistribution techniques, the ecological considerations are not sufficiently defined. The comparisons, therefore, are more operationally oriented in this study, and the potential long-term effects must be given more consideration when a specific spill is considered. In many cases, the best overall approach may be to utilize combinations of approaches, such as using skimmers on the thicker oil patches or near the source, and using dispersants on the thin areas.

In this study, a comparison of skimming methods was first made, followed by a comparison of the best of the skimming methods with the redistribution techniques of dispersing, burning, and sinking. Advanced concepts for dealing with oil spills were also considered.

Skimmers

Oil skimmers that may be considered for use in extreme wave conditions can be separated into two general categories: skimmers that recover oil from the thickened pool in the bucket

of a long oil boom towed in a U-configuration, and skimmers that act on the relatively thin slick more or less directly. The first category can be divided further into cases where the skimming function is integrated with the boom and where the skimmer is independent of the boom structure. In the first of these two cases the skimmer should be sufficiently small and light so that it conforms to the free surface as well as the boom itself.

A distinct advantage of boom systems over direct acting skimmers is the increased sweep width, achieving high encounter rates. Some of this advantage is lost, however, by the low current limitation on boom effectiveness. Booms do not have to contain all of the encountered oil, however, as long as sufficient thickening occurs to make the skimmers effective. The skimmers used with booms usually required large thicknesses of pooled oil to effect high transfer rates that are relatively free of water.

The second general category of (direct) skimmers can be employed in several ways, but generally a stable working vessel is used to provide support, propulsion, and logistic services. Either specially designed, dedicated skimming vessels can be utilized with the skimming equipment permanently installed, or vessels of opportunity can be employed. This second general skimmer category can operate directly in thin (1-mm) slicks.

These skimmer categories emphasize more the strategic concepts in dealing with oil slicks, rather than the variations in specific skimming mechanisms that are utilized in available skimmers. The term "skimming mechanisms," refers to the fundamental oil-water separation principles that are utilized in skimming, such as weir separation, oleophilic material contact (disks, foams, fibers), gravity enhanced weir-type separation (cyclone devices), etc. These fundamental mechanisms are affected mainly by the oil properties and slick continuity, and not necessarily by the sea state or weather, per se. However, the platforms required to support these mechanisms (ships, floats, etc.), and the devices utilized to improve slick continuity (containment booms or localized barriers) are heavily influenced by sea conditions.

Some of the literature on skimmers claims operation in fairly high waves, implying a high sea state capability. However, operation in swell, without high frequency waves present (the short wave-length, steep, wind-driven waves), is considerably different than operating in fully-developed seas of the same "wave height." Many systems fail to operate effectively in relatively low, but steep, waves, which are still present in the higher significant-wave sea states. Thus, a claim to operate in 10-foot waves (swell -- average period on the order of 10 seconds) does not necessarily mean a capability of operating effectively in 10-foot significant wave height seas (fully-developed and wind-driven, 6-second average period).

Brief descriptions of typical skimming mechanisms and the ways in which they can be utilized are given in the following sections. These are then used for reference in the later discussions of overall skimming system concepts.

Weir Skimmers: Several skimmers utilize a weir to separate a thickened oil layer from the underlying water. Wave conformance of the weir lip is extremely critical, and this mechanism is best utilized in skimming barriers where the support framework (in this case, the barrier itself) conforms well to the surface in higher sea states. Double-weir systems (two weirs in series) will improve separation, but system complexity increases dramatically.

Oleophilic Disks: This skimming mechanism utilizes disks that rotate in a thickened pool of oil, lifting the oil from the surface where it can be scraped off the disks and recovered. The Coast Guard OWORS and other commerical systems utilize this concept. Oil booms are required to thicken the oil sufficiently. Various hull-shaped or other float devices are used to support the disk arrays and associated machinery.

Surface-Piercing Oleophilic Belt: In this mechanism, an endless, rotating, porous (foam) belt dips into a thickened pool of oil and removes oil by sorbent action, while water drains back to the surface. This mechanism requires a heavy supporting structure, and is usually employed on a vessel system. Performance of this concept in tests at OHMSETT[13] was severely degraded with waves and high skimming speeds (> 1 knot), partially because of the pitching motion of the surface-piercing belt.

Dynamic Inclined Plane: In this case, a rotating conveyor-type belt is not used to collect oil directly, but only guides the oil beneath the skimmer to a collection chamber. A 68-foot dedicated skimmer vessel utilizing this concept is among the largest that has been built and used successfully in open water. While this unit has not been tested in a limiting wave condition, its developers have invoked linear scaling to predict that the 65-foot unit will recover oil satisfactorily in 4-foot waves. Similarly, a scaled up 160-foot dedicated skimmer is projected to have a 10-foot wave recovery capability (sea state 5) at speeds up to 3 knots[14]. While this scaling may be justified by comparisons between smaller units over a limited range of sizes, extrapolation to large scale must be viewed with caution. The turbulent wave energy does not scale linearly, for example, so that interactions between the skimmer and waves may be more pronounced in the extreme cases.

Cyclonic Separator: This mechanism employs a cyclonic separator attached to the side of a support ship, and uses the momentum of the water flowing past the ship to separate the oil from the water encountered by the device. The advantages of this system are its simplicity, ease of maintenance (with all pumps on the deck and no moving parts overboard), and its rigid attachment to the vessel due to the supporting framework which makes it easy to deploy.

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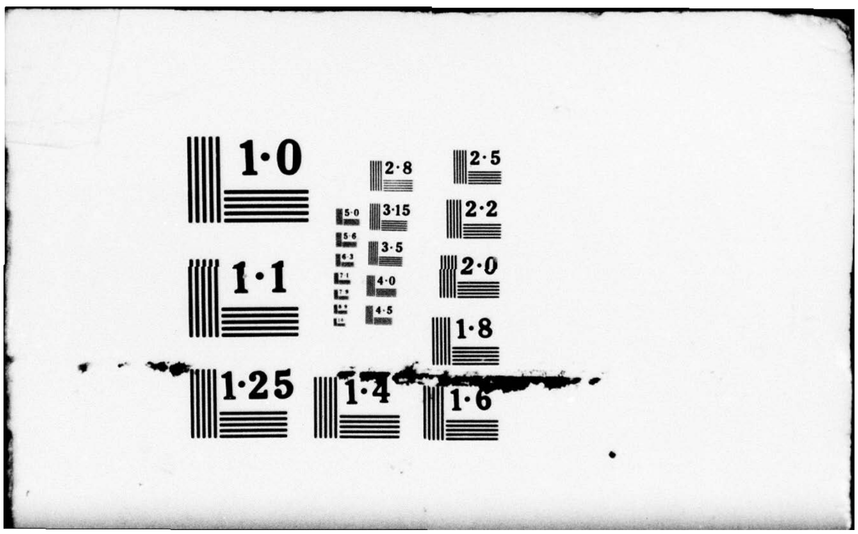
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The disadvantages include variable performance and extensive rigging preparations. Because the skimmer is rigidly fixed to the side of the support ship, it cannot follow the waves independently of the ship, and its performance suffers accordingly. In some tests[15], the throughput efficiency dropped to five percent in wave conditions. The "shadowing" effect from the ship's bow wave could also reduce the encounter rate significantly. The framework necessary to support the skimmer and to lift it out of the water must be installed on the support ship, which could increase the response time to a spill.

Sock Skimmer: The "sock-type" skimmer is a unique type of skimmer designed for a vessel of opportunity. The sock concept is to have a covered oil boom arranged on each side of the vessel. A 25-foot wide opening is maintained by a rigid framework, which also provides attachment points for the tow lines. The cover on the top of the boom has several oil suction ports to remove the oil as it collects near the back of the sock, which also serves as a wave damper.

In principle, the sock skimmer floats independently of the support vessel, and thus should conform to the low frequency waves. The high frequency elements are damped out by the skimmer and should not interfere with the skimming operations. If the vessel is headed into the waves, the bow slamming effect could force the oil away from the skimmer. Skimming with the waves avoids this problem, and skimming could be effective in this manner.

The durability of the design in waves and its ability to follow the waves in a sea state 4 and higher are highly suspect.

Zero-Relative-Velocity (ZRV) Sorbent Mechanisms: ZRV systems can operate at high forward speeds (3 knots), because the sorbent lies "stationary" on the water for a brief period. These systems fall into three classes -- loose sorbent, continuous rope (MOP)

sorbent, and continuous belt sorbent. Each of these concepts solves the wave conformance problem with a different degree of wave compliance, with loose sorbents giving potentially the best conformance and belt sorbents the least. Each of these classes of sorbent systems can also be arranged into a configuration suitable for vessel-of-opportunity applications, dedicated skimming systems, etc.

Loose sorbents: These are cubes or slabs of absorbent foam (usually polyurethane), which are broadcast out over the oil slick. A vessel proceeds through the broadcast area and harvests the oil-soaked foam from the surface. The oil is then squeezed out, and the foam is broadcast again. The distribution and harvesting can be combined on one vessel so that a closed circuit is formed. The foam is distributed at the water surface (to minimize wind effects) near the bow and the oil and sorbent are concentrated by booms or by the ship's hulls (catamaran-type vessels) to feed into a porous conveyor harvester near the stern or amid ships. The sorbent is squeezed to remove the oil and then routed forward for another cycle.

The advantages of a loose sorbent system are the true zero-relative-velocity (ZRV) operation that is possible, the three-dimensional compliance of the sorbent to the water surface, and the high recovery efficiency of the system. Some of the disadvantages of such a system are similar to those of a boom and skimmer sweeping system. If concentrating booms are used to guide and funnel the sorbent and oil to a collector, the problems of containing the oil soaked sorbent with a boom are only a little easier than containing the oil itself.

The sorbent collector is a surface-penetrating open-mesh conveyor belt which must have some wave following provision to prevent excessive drag or sorbent loss. The wave compliance might also prevent the water motion from pushing the sorbent away

from the collector. With the wave following mechanism, the harvester could be a complex and heavy piece of equipment which would be difficult to mount on a vessel of opportunity. Unless large "slabs" of sorbent are used, this system may suffer from sorbent particle losses that would necessitate large make-up feed rates (a logistics problem). It may be desirable to have a secondary chip containment screen behind the lift to minimize losses. The mechanical complexity of these sorbent systems is also a disadvantage, although on a dedicated skimming vessel these problems could be minimized.

Rope and belt sorbents: To avoid the problems of sorbent containment and harvester mechanisms, and still retain sorbent advantages, rope and belt sorbent systems were developed. Instead of a harvester trying to collect loose sorbents, the rope or belt configuration can be lifted from the water in a continuous manner. While small waves are tolerated by these concepts, it is not clear (particularly in the case of the belt-type ZRV) that wave heights on the order of eight feet can be followed.

A belt mechanism is best suited for use in an independent or dedicated skimming device. The relatively wide belt can only be controlled if it is operated as a two-dimensional loop. The rope can also be utilized in this type of skimmer, but because it is not restricted by a width dimension, it can be utilized in a wider variety of configurations. One such configuration, as proposed in a Navy study[13], runs the rope from a deck-mounted squeezing machine onto the water surface, out to a boom-mounted pulley at right angles to the vessel, and back again to the squeezer. Other arrangements can also be conceived that will utilize the rope's ZRV capability more effectively, while still maintaining minimum overboard weight and total control of the device from aboard the vessel. Such a system, although untested at this point, appears to offer the most promise for VOSS application in higher sea states.

5.1 Barrier With Independent Skimmer Inside Barrier

System Objective

To contain a portion of a slick and thicken the oil for more efficient recovery by an independent skimming device.

System Description

The system is composed of:

1. Barrier, approximately 600 feet long, providing a 400 foot opening

2. Skimmer for removing oil from the apex of the boom

3. Storage system for recovered oil

4. Towing vessels for towing the boom, skimmer, and recovery device

5. Oil-water separator (optional)

6. Slick surveillance, for directing the skimming system to new patches of oil.

7. Delivery system

Barrier: The most highly developed oil boom designed for slick recovery in extreme weather is probably the U.S. Coast Guard open water oil containment (OWOCS) boom. Good wave conformance was achieved by providing an external tension member to carry the main loads. As with any boom, collection is limited to relative towing velocities on the order of one knot. In comparative tests with many other booms, the OWOCS has shown the best all around performance, in terms of wave conformance, containment ability, strength, ease of handling, and reliability.

A second boom design that is comparably rugged and conforms well to the surface is the bottom-tension barrier utilizing pneumatic flotation. Disadvantages of this boom in relation to the USCG boom include: non-automatic inflation of flotation members for deployment, and greater susceptability to splashover of waves. Reel storage is an advantage, however.

<u>Skimmer</u>: Several types of skimmers are available that could be utilized. Three concepts for using them are:

1. The skimmer is tethered in the apex of the barrier and controlled through an umbilical by a vessel located a substantial distance from the skimmer. This system is depicted by the present Coast Guard OWOCS/OWORS approach.

2. The skimmer is solely supported by a hydraulically-actuated boom system mounted on a vessel operating next to the barrier. The mode of operation would require that after a boom had swept up some oil, the support vessel would be brought alongside the boom and the skimming head would reach out over the boom and transfer the collected pool to tanks. The skimmer head is relatively isolated from the support vessel and free to conform to the wave motion inside the boom. Commercial systems utilizing this concept use an oleophilic disk skimming mechanism, similar to the OWORS. This type of unit has been used in 3-meter high waves on a blowout in the North Sea.

3. The skimmer is umbilically controlled from a remote vessel, as in the first case, but it is also self-propelled and thus not tethered to the barrier. Various skimming mechanisms can be utilized (one commercial system utilized the oleophilic disk concept).

<u>Interim Storage System</u>: For the rates of oil recovery under consideration, a barge or similar vessel (small Navy oiler, etc.) is assumed. A typical 50,000-bbl barge would hold the output of over 30 hours skimming, at 1000 gpm. The largest bladder-type storage devices (6,918-bbl) would hold the output of less than 5 hours pumping at the same rate. Storage vessel change-out frequencies of more than one per day are considered undesirable, because of the time and hazards involved with such operations in heavy weather. Barges would make good work platforms in most cases, although when nearly full, deck wetness could be a problem.

<u>Towing vessels</u>: The towing vessels must be capable of low speed towing, and also of providing a stable platform for personnel. Vessels with low speed capability (1 kt) and maneuverability are not common and are usually vessels having variable pitch propellers, twin screws, bow thrusters, or diesel-electric drives.

For this approach, a 160-foot or larger vessel is assumed. Offshore supply boats, Navy ARS (marginal) or ASR vessels, certain fishing boats, WLB buoy tenders (marginal), and larger ocean going tugs would also be acceptable.

For the close-ship support concept, where the skimmer is supported from a hydraulic boom on a nearby ship, the ship itself must have high maneuverability and provide a stable support platform. Operation in beam seas might be necessary to bring the ship alongside the barrier without incurring damage from overriding. This, however, gets into severe roll problems which make wave conformance difficult and provide considerable stress to operating personnel.

Oil-Water Separator: In this case, the barge is assumed to act as a separator, with excess water being decanted overboard as the barge is filled. Although this may result in some oil or emulsion being pumped back onto the sea surface, the effects will be inconsequential. High-capacity portable separators mounted on the barge deck could be used, also, but each barge utilized must have one installed.

Slick Surveillance: Guidance for the towing operation should be provided by aircraft or medium endurance or larger cutters.

Delivery system: Probably the best delivery system for heavy weather is a 165-foot or larger offshore supply boat, equipped with an A-frame and a stern roller. The size of such a vessel makes it a good platform to work from in assembling the skimmer and preparing the barrier for launching. The entire system can be preassembled on deck, even to the point of starting the skimmer mechanism (unless remotely startable) and passing the transfer hose beneath the barrier. A possible layout for the concept No. 1 skimmer just before launching is shown in Figure 4. None of the launching operations are expected to be easy.

Use of the Coast Guard sled in heavy weather would offer no advantages over the supply boat delivery method. Transport speeds would be limited by towing vessel motions and motions of the sled itself. At the work site, assembly would have to be done in the water, which would be undesirable in heavy weather.

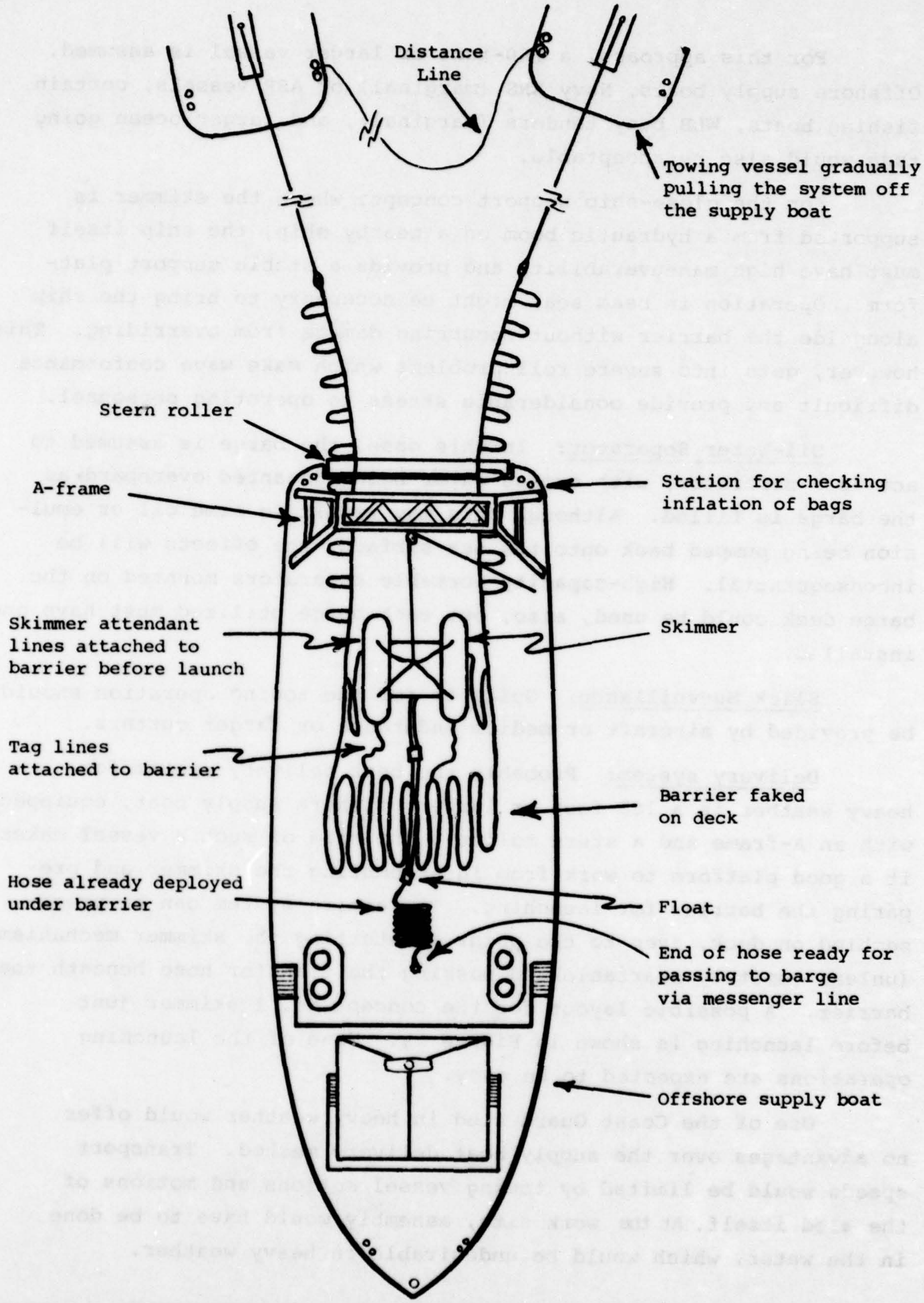


FIGURE 4. INDEPENDENT SKIMMER AND BARRIER FOR DISTANT SHIP SUPPORT -BEFORE LAUNCHING

System Operation

One concept for deploying and operating the concept No. 1 system is as follows: The equipment is delivered to the site by the delivery vehicle and launched with the aid of the boom towing vessels. The delivery vehicle then becomes the support platform for the skimmer. A tow vessel brings a receiving barge alongside the support ship and transfers the barge towline over. A hose is then run from the support ship to the barge, for transferring the oil to the barge. To change out a barge, the hose on the full barge is disconnected, and the towline is passed to a standby tug to tow the barge away. This process is reversed to take on a new, empty barge. Figure 5 shows the concept No. 1 skimmer deployed. Other methods for deploying the systems can be conceived.

Ratings

Ratings are presented in Tables 13 and 14.

All three skimmer utilization concepts are discussed below where appropriate, but ratings are only presented for the first two. The third concept has many problems in common with the first two.

Performance: With the wide sweep width provided by a barrier, a high oil encounter rate and a potentially high recovery rate is possible. The performance of the independent skimmer systems (concept 1), such as the Coast Guard's OWORS/OWOCS, has not been verified in high sea states, but it seems likely that the limiting factor will be tied to the inability of the boom to maintain a discreet oil pool. Wave action tends to be intensified in the bucket region by reflections and boom generated waves. Oil thicknesses above 4-6 inches are unlikely, even in good conditions. The barrier was designed for Sea State 3, but a reliable estimate on the limit for collecting and containing oil is about eight feet[16] (maximum breaking wave height for barriers now available) which nearly corresponds to a sea state 4 (10 m/sec wind).

Viscous oils may slow recovery somewhat because of pressure drop in the hoses. Depending on the skimming mechanism (disk-type skimmers are utilized in all three of the concepts listed above) the actual recovery rates and efficiency of the skimmer may improve with higher viscosities.

FIGURE 5. INDEPENDENT SKIMMER AND BARRIER WITH DISTANT SHIP SUPPORT -- FULLY DEPLOYED

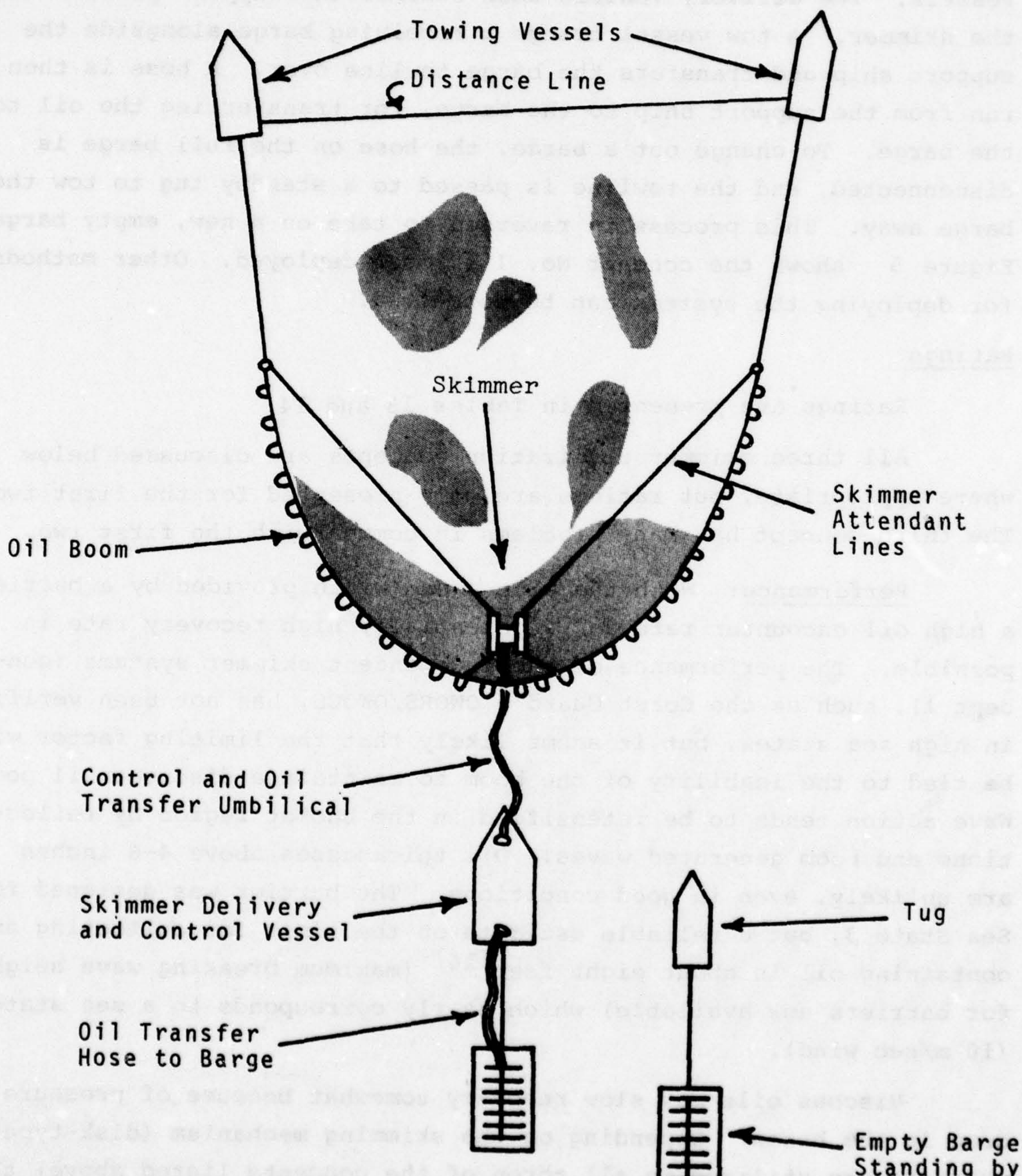


TABLE 13. INDEPENDENT SKIMMER AND BARRIER WITH DISTANT SHIP SUPPORT (OWORS/OWOCS)

Ratings vs. Scenarios		Sea State	Sea State 4		Sea State 5		Sea State 6	
Wt.	Factor	Oil Viscosity	Medium Crude 30 cs	Heavy Oil 5000 cs	Medium Crude 30 cs	Heavy Oil 5000 cs	Medium Crude 30 cs	Heavy Oil 5000 cs
0.30	Performance		.7	.9	.2	.2	0	0
0.15	Operational Control		.2	.2	0	0	0	0
0.15	Personnel		.4	.4	.3	.3	.2	.2
0.15	Mobilization & Setup		.2	.2	.1	.1	0	0
0.10	Support Logistics		.6	.6	.5	.5	.4	.4
0.05	Reliability		.2	.2	.1	.1	.1	.1
0.05	Long Term Environmental Effects		1.0	1.0	.8	.8	.6	.6
0.05	Survivability		.3	.3	.1	.1	0	0
		Total	.40	.43	0	0	0	0

TABLE 14. INDEPENDENT SKIMMER AND BARRIER WITH CLOSE-SHIP SUPPORT (SKIMMER SUPPORT BY HYDRAULIC BOOM ON SHIP)

Ratings vs. Scenarios		Sea State	Sea State 4		Sea State 5		Sea State 6	
Wt.	Factor	Oil Viscosity	Medium Crude 30 cs	Heavy Oil 5000 cs	Medium Crude 30 cs	Heavy Oil 5000 cs	Medium Crude 30 cs	Heavy Oil 5000 cs
0.30	Performance		.5	.6	.1	.2	0	0
0.15	Operational Control		.4	.4	0	0	0	0
0.15	Personnel		.4	.4	.2	.2	0	0
0.15	Mobilization & Setup		.4	.4	.1	.1	0	0
0.10	Support Logistics		.4	.4	.3	.3	.2	.2
0.05	Reliability		.4	.4	.2	.2	.2	.2
0.05	Long Term Environmental Effects		1.0	1.0	.8	.8	.6	.6
0.05	Survivability		.3	.3	.1	.1	0	0
		Totals	.45	.48	0	0	0	0

None of these concepts is considered practical in Sea State 5 or greater, because of the likelihood of not containing sufficient oil.

Operational Control: The three concepts above each have different operational control problems, although one of the major problems expected is in maintaining a 1-knot or less tow speed for the boom, while still maintaining control and steerage way in heavy seas. The least controllable concept is the first one, where many separate items of equipment must work together at all times. In the second concept the danger of overruning the barrier is great. Also, the problems of controlling the skimmer head by manipulation of the hydraulic crane will be very difficult, even in Sea State 4. Another disadvantage of this system is that it may not work effectively under way at the boom speed. In the third concept, remote control of the skimmer may be difficult to accomplish effectively without danger to the barrier.

Personnel: With no swimmers required to be in the water for launching, the critical times for personnel will be in performing maintenance on the skimmer, and in changing oil storage barges. Maintenance or repairs on the skimmer in the water could probably not be accomplished even in State 4 seas. In this respect, the skimmer in the second concept can be more easily maintained and repaired because it can be brought rapidly back on board the support vessel. With the second concept, severe rolling or pitching motions, depending on the location of the unit on the vessel, would present difficult working conditions for personnel during skimming.

Mobilization and Setup: Considerable problems can be expected in obtaining the required support systems (two low-speed tow vessels, a launching work-boat, barges and barge towing vessels), unless prior arrangements have been made. Some of the setup problems were discussed previously, and problems with making initial connections can be expected in all concepts.

Support Logistics: Logistics problems will be considerable because of the quantities of oil to be handled, and because of possible problems in the timely switching of receiving barges. On-site burning is conceivable, and is discussed elsewhere. At present, no adequate burning systems exist.

Reliability: The barrier probably has more demonstrated reliability than the skimmers, although not enough operating experience with any of the configurations discussed has been gained to ensure high reliability of the components. Particularly vulnerable to breakdown is the independent skimmer, which may contain the engine, hydraulic power supply, and many moving parts. The risk of damage to the barrier is fairly high in all cases, especially the close-support skimmer concept.

Long-Term Environmental Effects: Physical "lifting" of the oil from the sea surface is perhaps the most environmentally sound method of pollution control.

Survivability: The probability of barrier survival is fairly high if one end of the tow line is released, allowing the barrier to stream out in the wind and current. However, skimmers are less likely to survive with minimal damage, and attachment of the skimmer to the barrier during survival could be detrimental to the barrier in terms of chafe, and tension line or transfer hose fouling. The more easily recoverable skimmers of the second and third utilization concepts, will increase the survivability of these systems.

Time Considerations

In the independent skimmer system, the critical time areas are in the setup phase and in obtaining vessels to support the operation. Assuming that offshore supply boats were used for launching the system, the setup procedure would represent a considerable improvement over previous attempts to set up similar systems using only Coast Guard vessels and swimmers in the water. Even then, the complexity of the system could require many time-consuming operations. The time to acquire and transport a receiving barge could also be great, and the actual critical path of the operation could involve the barge acquisition phase, rather than the skimmer/barrier setup phase, depending on the relative availability of skimmer-support and receiving vessels. An example time-line diagram for this system is shown in Appendix D.

Coast Guard Impacts

In the concept No. 1 skimmer, successful launching will require vessels similar to offshore supply vessels, which can be chartered for $3K to $4K per day (if available), or purchased for on the order of $2.5M for a 4,000-hp vessel. Problems involving oil storage are similar to other skimmer systems. This system is relatively well developed, but it is not particularly suited to heavy weather operations because of the operational control problems.

A concept No. 2-type skimmer also involves severe control problems in heavy weather. A typical skid-mounted skimming system costs on the order of $180K, and should be supported on a vessel having both bow and stern thrusters, similar to supply/work boats presently in use in the North Sea. The No. 2 and 3 concepts do not appear to offer sufficient advantages over the skimming barrier concept in heavy weather to justify their procurement or further development by the Coast Guard.

Related Development Areas:

Hose systems for transferring recovered oil to receivers
Continuous burning systems for recovered oil
Methods for receiver towing and transfers
Prearrangements for obtaining barges and support vessels
Vessel-mounted slick surveillance system

5.2 Barrier System with Skimmer Part of Barrier Envelope

System Objective

To provide a barrier to a slick, and continuously remove the oil from the barrier at the apex.

System Description

The system is composed of:

1. Coast Guard skimming barrier, or a vessel-type skimmer with herding barrier attached.
2. Storage system for recovered oil.
3. Towing vessels for towing the boom, skimmer, and recovery device.
4. Oil-water separator.
5. Slick surveillance, for directing the skimming system to new patches of oil.
6. Delivery system.

Skimming Barrier: The skimming barrier is basically a Coast Guard barrier modified with weir-type openings in the sections near the apex to withdraw the contained oil, with a hydraulic-powered diaphragm pump system to transport the oil to a receiving vessel. The sea-keeping capabilities of the skimmer section will be similar to the barrier section. The pumping rate could be from 600 to 1,000 gpm, but with the limited power supply and the longer hose lengths needed for safety in heavy weather, capacities can be expected to be less than this. Also, because the weirs pick up considerable water, recovery efficiencies and oil collection rates will be lower. Viscous oil is not a severe problem because enough water is usually collected to keep most of the oil in suspension.

The vessel-type skimmer with herding barrier attached is one of the oldest concepts for skimming oil. Manned or unmanned skimmers with various skimming mechanisms can be utilized, along with various types of barrier. The principal problem in rough seas is that the skimmer motions disrupt the barrier function, causing oil losses and potential barrier damage.

Oil Storage System: The size and characteristics of the storage vessel will be similar to the independent skimmer case. The skimmer may recover considerable water, and oil-water separation should be carried out either by decanting within the recovery vessel, or with a separate system.

Towing and Support Vessels: For towing a skimming barrier, or a skimmer with herding barrier attached, about the same size and type of vessels are required as for the independent skimmer and barrier case.

Oil-Water Separator: This is more important than in the independent skimmer case, as mentioned above. Rigging the receiving barge to decant may be a solution, although commercial oil-water separators are also available that can perform the gross separation necessary.

Slick Surveillance: Same as independent skimmer and barrier case.

Delivery System: Delivery is easier with the skimming barrier because only one major unit is involved. In this case, launching off the deck of a buoy tender is more feasible, although a work boat with an A-frame would be better. At least there is more flexibility in the type of vessel that can be used with this system.

For the skimmer with herding barrier attached, the problem can approach that of the independent skimmer case, and a similar approach could be used. The skimmer may also be towed to the site (time consuming), if it is pre-rigged with barriers that can be stowed on the skimmer and quickly deployed when on-site.

System Operation

In principle, this system operates just like the independent skimmer and barrier case. The system is deployed and is towed into the thick part of the oil for recovery. The skimming barrier system offers more flexibility in that it is easier to recover and shift to a new area (say in a spread out slick), especially if a supply boat is used for recovering and launching.

Ratings

Ratings are presented in Tables 15 and 16 for the skimming barrier and the skimmer-herding barrier systems, respectively.

TABLE 15. SKIMMING BARRIER

Ratings vs. Scenarios		Sea State	Sea State 4		Sea State 5		Sea State 6	
Wt.	Factor	Oil Viscosity	Medium Crude	Heavy Oil	Medium Crude	Heavy Oil	Medium Crude	Heavy Oil
0.30	Performance		.8	.7	.1	.1	0	0
0.15	Operational Control		.3	.3	0	0	0	0
0.15	Personnel		.6	.6	.5	.6	.3	.3
0.15	Mobilization & Setup		.5	.5	.3	.3	.1	.1
0.10	Support Logistics		.6	.6	.5	.5	.4	.4
0.05	Reliability		.4	.4	.3	.3	.1	.1
0.05	Long Term Environmental Effects		1.0	1.0	.8	.8	.6	.6
0.05	Survivability		.4	.4	.1	.1	0	0
		Totals	.57	.55	0	0	0	0

TABLE 16. SKIMMER WITH HERDING BARRIER

Ratings vs. Scenarios		Sea State	Sea State 4		Sea State 5		Sea State 6	
Wt.	Factor	Oil Viscosity	Medium Crude	Heavy Oil	Medium Crude	Heavy Oil	Medium Crude	Heavy Oil
0.30	Performance		.5	.5	0	0	0	0
0.15	Operational Control		.3	.3	0	0	0	0
0.15	Personnel		.5	.5	.4	.4	.2	.2
0.15	Mobilization & Setup		.2	.2	.1	.1	0	0
0.10	Support Logistics		.6	.6	.5	.5	.4	.4
0.05	Reliability		.3	.3	.2	.2	.1	.1
0.05	Long Term Environmental Effects		1.0	1.0	.8	.8	.6	.6
0.05	Survivability		.3	.3	.1	.1	0	0
		Totals	.40	.40	0	0	0	0

Performance: The good wave conformance of the skimming barrier in a wide range of wave conditions means that the weirs will usually be close to a thickened oil layer, and minimal disturbance of the oil pool by the skimmer section should result (at least it should not be much more than the barrier itself). However, the limited power capability of the skimming barrier, and the relatively low recovery efficiency (high water pickup) inherent in single-stage weir-type collecting devices, will probably result in low recovery rates. Viscosity should have little effect on recovery, at least to a point.

With a dissimilar skimmer and barrier, the extreme mismatch in wave response can greatly disturb the oil pool and result in little oil present to be collected. If weir-type skimming mechanisms are not utilized, viscosity could have more of an effect, with high viscosities possibly being easier to collect (again, to a limit).

Oil recovery in Sea State 5 will not be good with either of these systems, and with the dissimilar skimmer and barrier system even recovery in Sea State 4 may not be good, depending on the components.

Operational Control: Operational control problems are only a little less severe than the independent skimmer and barrier case. However, rapid transport to remote areas of the slick should be easier with a skimming barrier, as recovering and launching the system should be easier.

Personnel: Personnel considerations are nearly the same as the independent skimmer and barrier case. With possibly fewer mechanical parts to deal with in the water (skimming barrier case), the probability of personnel problems is less. Also, risks to personnel during launch and retrieval should be less. With a vessel-type skimmer, personnel problems in boarding and maintenance could be the same as the independent skimmer and barrier case.

Mobilization and Setup: Mobilization and setup considerations are basically the same as for the independent skimmer and barrier case. With the skimming barrier, however, more flexibility in a launching vehicle may be possible, as a separate large skimmer is not involved. The effect of the sea state may be somewhat less.

Reliability: At the current stage of development, the transfer pumps on the skimming barrier have probably the least reliability, and would pose the most serious difficulties if problems developed during operation. With three pumps on line some redundancy is provided. If problems developed, repairs would have to be made on deck and a long delay would ensue. The reliability problems with the dissimilar skimmer and barrier system could easily be worse than the independent skimmer and barrier case, especially in the barrier where the point of attachment to the skimmer is highly stressed.

Long-Term Environmental Effects: Long-term effects should be minimal, except that low efficiencies may mean that more of the oil escapes to cause damage elsewhere.

Survivability: Survival considerations are similar to and probably better than the independent skimmer system, except in the case of the dissimilar skimmer and barrier.

Time Considerations

For the skimming barrier, setup procedures could be similar to the independent skimmer case, except that fewer and less complex operations would be required. Once operating, time considerations would be about the same, except for a possible lower skimming rate. The problems of obtaining support (launching) vessels and oil receivers would be similar to the independent skimmer case, except that procurement of these vessels probably would be on the critical path. (Transfer of the skimming equipment to the staging area is assumed to be accomplished within approximately six hours.) The example time-line diagram in Appendix D for the independent skimmer case also shows the similarity with the skimming barrier case.

Coast Guard Impacts

Vessel Impacts: Vessels are required to tow the system; support the power unit, separator, and other controls; assemble and launch the system; support or tow the oil receiver (barge or bladder), and/or serve as an oil receiver itself (tankship). A minimum of three vessels are required--two for towing and one for following the barrier and providing the support functions. The WLB buoy

tender with bow thruster appears to be a reasonable low-speed towing vessel for heavy weather, and the 210 cutter may also be satisfactory. Certain Navy and commercial vessels would also be satisfactory, although the older Navy vessels would probably need bow thrusters added to provide adequate performance.

For launching and supporting the skimmer-barrier, a buoy tender could probably be used. This is not as desirable as an offshore-supply type of ship, but it could probably be done. Unless special tankage was installed in the holds, no oil could be stored on board (no room for pillow tanks on the deck). This would necessitate towing a barge to store the oil, which is an added complication to the system.

A typical oil-water separator commonly used on tankers (gravity type), having a capacity of 900 gpm, would weigh on the order of 19 tons wet (5.4 tons dry) and measure 15 feet high by 8 feet diameter (two 260 gpm units would total 10 tons wet). A separator of this size could possibly be carried on the buoy deck of a WLB, or a similar system could be installed in the hold. This does, however, subtract from any on-board recovered oil storage capacity.

<u>Aircraft Impacts</u>: A helicopter support platform (preferably a 378-foot cutter), should be stationed nearby to provide a continuous vectoring capability.

<u>Siting and Manning Levels</u>: The siting factors being considered for low sea state responses should be applicable for heavy weather, also. Oil-water separators should be included in the equipment requirements, because water pickup in extreme weather situations will probably be higher than in calm water or swell. Cross-training of personnel to operate and maintain the separator will be required.

<u>Budgetary Requirements</u>: Costs to adapt existing Coast Guard OWOCS and provide pumping units are on the order of $70K per system. Oil-water separators may cost on the order of $35K-$50K (900 gpm), depending on the appurtenances (pumps, controls, etc.). Additional development costs are hard to estimate for the skimming system because of the advanced state of development existing already. However,

additional work is needed on deployment and handling methods for the integrated system, which could involve a small to medium development expenditure (mainly in-house). Another modification that should be considered for rough weather use is longer hoses (hydraulic and recovered oil) to allow more distance between the barrier and the skimmer support ship.

Several types of skimmers and barriers could be used to make up the skimmer-herding barrier type of system, but all suffer from motion mismatch problems in high sea states. Efforts have been made to develop decoupling links in the barrier section between the main barrier and the skimmer, but the results remain to be adequately tested in rough waves. Effective links could improve effectiveness of these systems. No combinations of known components appear to offer any significant operational, performance, or even cost advantages over the Coast Guard skimmer-barrier concept, and therefore, do not appear to justify further development consideration for heavy weather.

Related Development Areas

Hose systems for transferring recovered oil to receivers
Continuous burning systems for recovered oil
Methods for receiver towing and transfer
Prearrangements for obtaining barges and support vessels
Vessel-mounted slick surveillance system

5.3 Dedicated Skimmer

System Objective

To skim the oil from the surface in a completely self-contained system, which is highly maneuverable, seaworthy, and capable of rapid movements between cleanup locations.

System Description

The System is composed of:

1. A large (160-foot or larger) self-contained, manned, skimming vessel. Such vessels do not exist at this time, but preliminary designs are available based on scaled-up versions of smaller skimmers.

2. Bulk storage system for recovered oil.

3. Towing vessels for towing the storage vessel to and from the scene.

4. Slick surveillance system for directing the skimmer to scattered patches of oil.

Skimmer: Adequate heavy weather skimmers do not exist at this time, and new designs are in a state of flux, subject to potential customer requirements. Some common features and limitations of potential designs can be discussed, however.

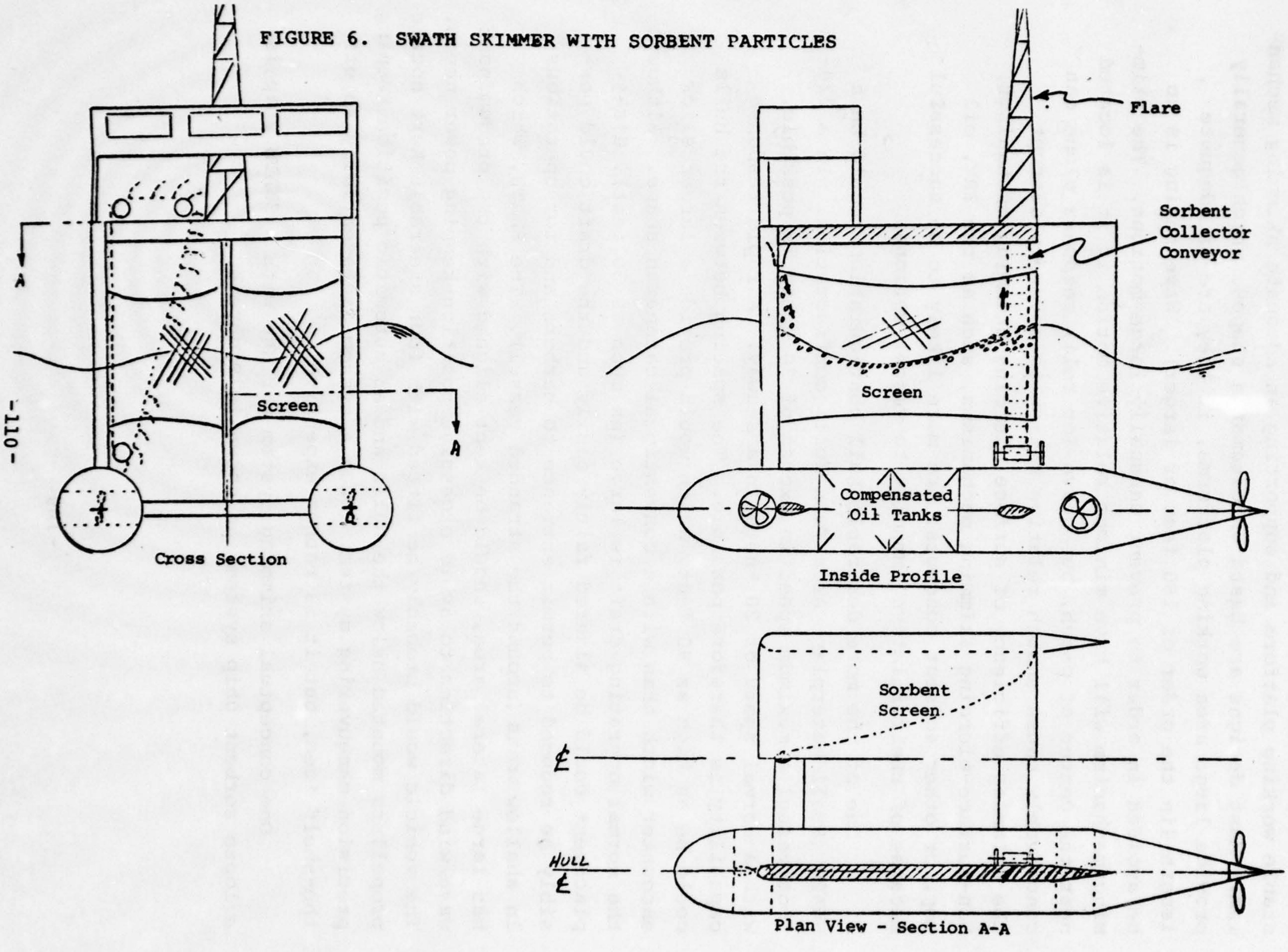
Because herding booms mounted on the skimmer are impractical in heavy seas, the maximum recovery rate is limited to the encounter rate of the skimming mechanism. A system with a 40-foot mouth opening, skimming a 5-mm slick at two knots, would encounter 1,000 gpm of oil. Recovery would be less than that rate depending on the throughput efficiency, which could range from less than 25 percent to 75 percent depending on the sea conditions, the oil type, and the skimming mechanism. Each pass of the skimmer would allow the remaining oil to thin out some more, so that the average encounter rate would be less than the above figure. The narrower the windrow, of course, the more effectively the skimmer would operate.

Design of the vessel is a compromise between providing a stable working platform and supporting an adequate skimming mechanism. Most designs are based on catamaran shapes, which generally provide large area working platforms, if they are of adequate length (in the order of 160 feet or larger). Wave tuning is to be avoided in order to prevent unusually large motions. The skimming mechanism will have minimum relative motion if it is located near the center of pitch, but heave (or roll) response alone can conceivably cause enough relative motion to severely disrupt the skimming efficiency of surface piercing skimming mechanisms. Non-surface-piercing skimming mechanisms, such as the ZRV, oil mop, or other sorbent concepts, are more likely to be successful because of their relative immunity to vessel motions.

One of the more desirable hull configurations would be a SWATH (Small Waterplane Area Twin Hull) configuration. In a 220-foot vessel a maximum speed in excess of 30 knots is possible, with a normal speed of 20 knots in a seaway. A rapid response capability is therefore possible. The spacing between the hulls could be as high as 90 feet, which would provide a larger slick encounter width than with a conventional catamaran shape. Although the normal operating draft is large (as much as 30 feet), displacement could be altered fairly easily and the draft could possibly be reduced to permit entrance to harbors and for operations in shallow areas (around the stranded vessel). The SWATH, which has large lateral area, should be kept aligned with the predominant wave/wind direction to avoid excessive position-keeping power needs. The vehicle would probably be fitted with four steerable Kort nozzle propellers mounted below the hulls and an automatic position-keeping/precision maneuvering system. Such a system is essentially an off-the-shelf item, but it is rather expensive.

One conceptual skimming system for use with a SWATH ship is a loose sorbent chip system, as shown in Figure 6.

FIGURE 6. SWATH SKIMMER WITH SORBENT PARTICLES



The mission would be primarily oil spill cleanup, but other capabilities could be included, as spill cleanup operations may account for only 5 to 10 percent of the operating time. Functions that could be desirable to have built into such a vessel include:

1. Oil spill cleanup (basic function).

2. Dispersant application.

3. Salvage (equipped with beach gear, compressors, pumps, etc.).

4. Towing (provided controllable pitch propellers were installed).

5. Search, rescue, and surveillance (functions of WMEC class cutters).

6. Buoy tending (with gantry and/or crane additions).

7. Other launch and retrieval capabilities (oil booms, skimmers, etc.).

8. Fire-fighting.

Storage Vessel: On-board oil storage capacity is relatively small in most of the potential large skimmer designs, being limited to only a few hours recovery capacity in all cases. Therefore, to realize the full flexibility of the dedicated skimmer concept, a large oil storage vessel (barge, lighter) must be standing by for periodic off-loadings. A barge or tankship is the best recovered-oil container, because of its seaworthiness and large capacity. Oil-water separation, if not performed on the skimmer, may be performed on the barge.

Towing Vessel for the Storage Barge: If only periodic off-loading of the skimmer is practiced, the towing vessel need not be capable of extended low speed towing capability. Other capabilities would be similar to those for any barge towing vessel.

Slick Surveillance System: A system for slick mapping is needed here similar to those needed by other response systems in order to make the most effective use of the skimmer in low visibility conditions.

System Operation: The system is operated in a straightforward manner. The skimmer reaches the scene of the spill, deploys into its skimming mode, and skims oil. Because of the inherent flexibility of the system, the ideal areas to attack are the windrows and other heavy concentrations. Transfers of recovered oil are periodically made to a barge standing by. A second barge should be on scene before the first one is filled. Dispersants could be applied (if permissible) during transit between the more concentrated oil patches.

Ratings

The ratings are given in Table 17.

Performance: The key to operation is the ability of the skimming mechanism to remain effective in the relative motions to be expected in the sea states under consideration. In this regard non-surface piercing skimmer mechanisms (floating sorbent surfaces) are more likely to be successful in heavy seas.

Average operational rate or effectiveness is affected by recovery efficiency, throughput efficiency, encounter rate (speed and thickness dependent), as well as by the requirement to periodically off-load oil from the skimmer. This effectiveness is expected to drop off rapidly in sea states above state 4.

Operational Control: A high degree of control is possible with this system, because it is entirely self-contained. Only the oil transfer operation should present any control problems. A trained permanent crew should simplify control on-board the vessel.

Personnel: Because of the relatively good platform capabilities of a large skimmer, personnel should be effective in most cases, as long as extended operations are confined to the midships region (where they should be, to minimize pitching effects).

TABLE 17. DEDICATED SKIMMER

Ratings vs. Scenarios		Sea State	Sea State 4		Sea State 5		Sea State 6	
Wt.	Factor	Oil Viscosity	Medium Crude	Heavy Oil	Medium Crude	Heavy Oil	Medium Crude	Heavy Oil
0.30	Performance		.6	.6	.2	.2	0	0
0.15	Operational Control		.9	.9	.6	.6	.4	.4
0.15	Personnel		.9	.9	.8	.8	.5	.5
0.15	Mobilization and Setup		.9	.9	.8	.8	.7	.7
0.10	Support Logistics		.4	.4	.3	.3	.2	.2
0.05	Reliability		.9	.9	.8	.8	.6	.6
0.05	Long Term Environmental Effects		1.0	1.0	1.0	1.0	1.0	1.0
0.05	Survivability		.9	.9	.7	.7	.5	.5
		Totals	.74	.74	.47	.47	0	0

The personnel on the barge may be more uncomfortable, unless adequate shelter is installed prior to deployment. Activities here would be minimal, however. In heavy weather the barge may have to settle for a partial load to avoid low freeboard effects (washover onto the clear deck of a barge).

Supply Logistics: The logistics problems are centered around the oil storage problems and the long transit times required for initial deployment in heavy weather. These problems are similar to the barrier system cases.

Mobilization and Setup: Mobilization can be time consuming if the skimmer is engaged in secondary activities at a remote location. However, obtaining a barge or tankship for receiving the oil can also be a problem, and the skimmer transit time may not be that critical. Setup for skimming will be minimal because all functions should be ready to go.

Reliability: Reliability for undesigned components is difficult to predict, but the system rates high in the fact that all equipment is on-board where it can be worked on, and trained personnel are available to make repairs.

Long-Term Environmental Effects: No detrimental effects are likely, except that all of the oil probably cannot be collected.

Survivability: The survival risks should be about the same as those for any vessel of this size, except that the SWATH may have better seakeeping characteristics.

Time Considerations

Although dedicated skimmers would presumably always be ready to engage in skimming operations, their multi-use function could have them occupied in a secondary operation a considerable distance from the casualty. The time to stop these operations and

transit directly to the spill site could also be on the critical path for this system. This time could easily be on the order of the receiving vessel procurement time, however, and the critical path could shift. The storage capacity on the skimmer, limited as it would be, would enable some skimming to be accomplished before the larger receiving vessel was needed. The frequent transfers to the receiving vessel could be time consuming, although high volume transfer pumps would help this situation somewhat. Time requirements for transfers could be on the order of 1/4 to 1/3 the actual skimming time. Appendix D shows an example time-line diagram for this system.

Coast Guard Impacts

Vessel Impacts: With a multi-mission capability that could be used to supplant the activities of certain Coast Guard vessels, some existing vessels may become unnecessary. For example, some of the older buoy tenders (WLB) with only 10-15-year remaining lives, could be decommissioned early and replaced with a new multi-mission dedicated skimming vessel. The new vessels could also preclude the need for certain older Navy ship functions, such as general salvage, towing and rescue (older ARS and ATF vessels).

Aircraft Impacts: Helicopters would be necessary to help in directing the skimmer toward new patches of oil.

Equipment Siting: To ensure that the skimmer was always available to reach the more remote locations within its area of responsibility, its secondary operations would have to be limited to a restricted range near the center of its coverage area.

For example, a 15-knot vessel operating in the vicinity of New York could travel to either Portland, ME., or Norfolk, VA., in less than 20 hours. SWATH ships could travel at speeds of 20 to 30 knots, thus reducing the transit time or extending the normal operating range.

Siting and storage costs would be minimal, as the ship would be operating most of the time and not occupying dock space or other shore-side facilities. Such siting requirements could probably be provided by existing facilities, if conventional draft vessels were involved. A deep-draft vessel, such as a SWATH ship, may require specialized facilities, in addition to limiting its area of applicability to deeper waters. Several vessels may need to be stationed around the coast where extreme weather spill response operations are likely (mainly in the Northeast).

Manning Levels: The manning level for a 200-foot vessel with a multi-mission capability (undefined) may be on the order of 5-10 officers and 50-75 enlisted, based on comparison with similar size Navy ships. However, with advanced equipment, normal crew sizes might be considerably less, especially if specialized personnel could be added to the crew only when needed, such as during cleanup or salvage operations. Specialized training would be required, and a pool of trained crew replacements would also have to be established and maintained. In addition, specialized maintenance, repair, and other support services would be required, thus increasing the total manning level.

Budgetary Requirements: The estimated prices for catamarans, SWATH ships and monohulls of comparable length and function are shown in Table 18 . When fully outfitted for oil skimming (sorbent system), with oil storage, heavier lifting capacity (20-ton boom), and salvage gear aboard (beach gear, air compressors, heavy mooring, etc.), the price could be in the range of \$12M-\$15M. Annual operating costs could be on the order of \$1.5M-\$2M per ship, including 50-man crew, fuel, maintenance, supplies, and other logistic support functions.

A complete development and design effort for a new ship would be required (6-8 years), involving a major development expenditure in the order of \$5M-\$10M, exclusive of the lead ship. A careful

TABLE 18. PRICES FOR COMPARABLE SIZE SHIPS

	Monohull	Catamaran	SWATH
LOA (ft)	200	180	170
LWL (ft)	176	130	123
BEAM (ft)	37	55	62
DEPTH (ft)	16	32	43
DRAFT (ft)	9	8	18
CROSS STRUCTURE CLEARANCE (ft)		13	13
LIGHT SHIP Δ (TONS)	600	775	875
LOAD (TONS)	155	175	170
FULL LOAD Δ (TONS)	755	950	1045
SHAFT HORSEPOWER	2800	4000	3700
COST ESTIMATE (1978 Dollars)	\$6.6M	\$7.2M	\$8.1M

Assumptions

1. Compare monohull, SWATH, and catamaran hulls.
2. Mission - High service speed to reach location in the open sea and good seakeeping and maneuverability at loiter speeds for working on deck at sea.
3. Comparison basis is 16 knot service speed (80% full power with 60 ton payload.
4. Steel hulls.
5. One compartment damage stability.
6. Suitable for unlimited service (open sea).
7. Commercial construction suitable for USCG use.
8. Diesel or diesel/electric main propulsion.
9. Small crew.
10. Landing platform for small helicopter.
11. Outfit to include 5 ton crane, distilling plant, air conditioning, electric heat, pollution control, radio, radar and deck equipment for commercial type oceanographic work.
12. Reference: "Pacific Missile Range Workboat Configuration Study," May 16, 1975, Advanced Concepts Office Systems Development Department, NSRDC (Unpublished).

study would be required to determine the ship design required to operate in various severe and extreme sea conditions. The development of a new class of large, multi-purpose vessels could also have major funding implications in the Navy, where the replacement of certain older ships or ship functions may be considered. Rebuilding of existing large Navy catamaran vessels was considered, but it is not likely that this would be feasible or desirable.

Related Development Areas

Sorbent skimming mechanisms

Improved oil transfer systems

Vessel mounted slick surveillance systems

Barge handling and transfer systems

Floating hose

Flaring systems for recovered oil

5.4 Vessel of Opportunity Skimming System (VOSS)

System Objective

To form a skimming system using an available vessel, and adapting it by the addition of a highly flexible skimmer system.

System Description

At this time, no one particular skimming method stands out as being ideally suited for VOSS application in extreme weather. A few methods show potential but further development work is needed to determine feasibility. These methods are discussed later. All systems will require certain general functions and components, such as:

1. Vessel of opportunity.
2. Skimming device that can be placed over the sides of the vessel (including power supply, control, etc.).
3. Handling and lifting systems.
4. Storage systems for recovered oil.
5. Slick surveillance, for directing the skimming system to new patches of oil.

The last two items have been given general discussion elsewhere, and will not be discussed further.

Vessel: Depending on the location of the spill, the available vessels for offshore use with VOSS systems may be supply boats fishing vessels, small tankers, offshore barges, tugboats, or military vessels (USCG, Navy, etc.).

Preferably, the skimming device should work effectively from a wide variety of vessels. Pre-adapting certain vessels can shorten the time requirements to deploy the system, and is the preferred approach. However, if pre-adapted vessels are absolutely necessary to rapid deployment, then either (1) many vessels must be adapted to ensure availability, or (2) certain constraints must be placed on the few vessels that are adapted. Where few vessels are to be adapted, Coast Guard and certain Navy vessels may be the easiest to obtain in an emergency.

Several characteristics are necessary in a vessel before it can be considered a suitable platform for skimming operations. The vessel itself must be seaworthy in sea state 4 and above (this implies a length of 160 feet or greater). There should be a large open deck area for arranging the on-board support equipment for the skimmer, including power modules, lifting gear, pumps, manifolds, etc. Since most skimmers operate best at low speeds of advance, the vessel should be capable of operating continuously at less than three knots. Controllable pitch propellers and bow thrusters would be desirable. On-board storage of the recovered oil would also be desirable, especially for large spills at a distance from shore. This requirement could be avoided with the use of towable storage containers, but these would restrict the manueverability of the vessel. The likelihood of acquiring a suitable vessel on short notice without any previous arrangements could be very low in many areas of the U.S.

Various vessel possibilities are discussed in the following sections.

1. <u>Commercial Vessels</u>: Offshore supply boats would be the most desirable vessels for VOSS support, although trawlers could be used, and small tankships may also be available. Even small barges could be outfitted with VOSS skimming gear, and towed by several different types of vessels. Contamination of fishing vessels with oil is undesirable and the use of these vessels should only be considered if no other vessels are available.

Charter rates range from $3,000 to $4,000 per day, plus fuel and lube. Because of the high utilization of these versatile vessels, usually a notice of a month or more is required to charter them. However, in emergencies this time could probably be shortened. These vessels would be relatively easy to pre-adapt for skimming operations, although even post-adapting could be easy because of their simple layout and design. Pillow tanks could probably be used for oil storage. Internal tankage is usually available; however, present regulations may restrict the use of these spaces for recovered oil.

2. <u>Coast Guard Vessels:</u> The relatively common vessel classes that appear to be usable as VOSS support ships are the WLB 180-foot buoy tenders, and the WMEC 210-foot medium endurance cutters.

WMEC cutters have twin CP propellers and are suitable for ocean towing of up to 10,000-GT vessels. Fittings could be welded to the superstructure to adapt the skimming modules. Installation would probably have to be performed in port. On-board storage capacity is non-existent, but a fairly large barge could be towed aft to receive recovered oil. Pillow tanks for oil storage would be unfeasible because of reduced vessel stability.

The 180-foot WLB buoy tenders have a buoy deck with dimensions of approximately 35 x 40 feet, which could support the skimming gear. This is less area than a WMEC (helicopter deck), but it is located lower in the structure and can be serviced by the existing 20-ton boom. Little volume is available for oil storage, except for the forepeak tank (6280 gallons). A 12,000-gallon pillow tank (20 x 20 feet x 5 feet) would take up a large portion of the buoy deck and would only hold a half hour's oil recovery at 500 gpm. Approximately 10,000 gallons of tankage could also be installed in the two holds under the buoy deck.

Towing a barge with a WLB could be more difficult in heavy weather than with a WMEC because of the low power (1,200 hp), single-screw propulsion unit. Bow thrusters, which are available on certain WLBs, would help maneuverability. As with the WMEC, adapter fittings could be welded to the superstructure to accomodate special skimming systems. Response time with a WLB would be slower than with a WMEC because of its lower speed. However, small, lightweight skimming components could possibly be airlifted to a WLB, which could use its boom to support installation. Use of the boom while underway is not recommended, however.

3. <u>Other Government Vessels</u>: Several Naval auxiliary vessels could serve as VOSS support vessels, and could probably be pre-adapted. Such vessels are ASR's, ARS's, ATF's, ATS's, smaller AGOR's, small tankships, and possibly others.

Tankships have integral oil storage volume although the normal cargo may have to be off-loaded if the tankship is taken out of service for emergency use as a VOSS vessel. Certain AOG-class gasoline tankers are currently in reserve, and others have been transferred to MarAd for disposal. These vessels are approximately 300 feet long with about 3,000 to 4,000-dwt capacity, and

would probably be satisfactory for VOSS operations. They have twin-screw diesel-electric propulsion units and are probably well suited for slow speed operations.

The other vessels mentioned would have limitations similar to Coast Guard vessels, and would have to be examined on a case-by-case basis. In the limit, most of them could at least tow a barge or other container for storing recovered oil, and modifications to support the skimming modules would be minimal, depending on the design. Several ATF-type vessels (205-foot fleet tugs) are in MarAd reserve fleets, and could possibly be obtained for refurbishment as "dedicated" VOSS-type vessels.

Skimming devices: Various skimmer types have been proposed for use with VOSS systems. The types that appear to have the most promise for extreme weather use are the sorbent rope concepts, loose sorbent systems, and possibly the sock-type skimmer.

Other concepts that do not appear as attractive are some of the small, independent skimming vessels, which have been altered for remote control, usually with the power supply and control functions mounted on the support ship. The general arrangement usually includes a skimmer on each side of the support vessel with support poles or booms rigged for standoff and with funneling oil booms installed between the vessel and the skimmer. The standoff rigging and funneling booms are needed because as the vessel proceeds through an oil slick, the oil is pushed away from the side of the vessel. This effect would "shadow" an oil skimming device placed close to the hull. The distance that the oil-free shadow extends from the side of the hull depends upon vessel shape, speed, sea state, and vessel heading. The use of oil booms can lead to severe operating problems when the booms are connected to vessels having different motion characteristics than the boom itself. The performance of many of the skimmer designs would be adversely affected by waves because many of these skimmers were designed for harbor conditions. The coupling between the support ship and the skimmer can also affect the performance. The operational control and maintenance of these skimmers could be complicated with the skimming mechanism located remotely from the support vessel.

Lifting System: For the deployment of most systems, some type of lifting gear would be necessary. After transiting to the scene, the skimmers could then be lifted over the side into the skimming mode. The skimmers could also be hoisted back aboard the support ship for survival in worsening weather. However, lifting a fairly heavy or bulky device into or out of the water in rough weather could be extremely difficult and dangerous.

The required capacity of the lifting equipment would vary depending on the skimmer weight and deployment technique. Because available vessels may have anything from no lifting capacity to heavy A-frames over the stern, it may be best to depend on portable independent cranes that can be transported with the skimmer system. In some VOSS systems the lifting arm could be an integral part of the device, providing both support, power connections and oil transfer while the skimmer is in operation.

Ratings

Ratings are presented in Tables 19 and 20 for two cases--where the vessel of opportunity has been pre-adapted for a VOSS skimmer, and where the vessel was selected at random (post-adapted). The rope sorbent (mop) skimmer system was assumed in these ratings.

Performance: Performance of the system will be degraded by increasing sea state. The magnitude of the effect will probably depend a great deal on the characteristics of the support vessel. A rope pickup system could become less efficient due to the increased water velocities and turbulence, which would perhaps prevent the oil from adhering to the fibers. Performance in high viscosities would probably be better than in low viscosities. The overall performance of a vessel of opportunity system would probably be less than that of a vessel designed expressly for oil skimming operations.

Operational Control: This rates less for a vessel of opportunity than for a dedicated vessel. However, control will probably be easier than with barrier-type systems. A pre-adapted vessel and a trained crew should provide smoother operation than a post-adapted vessel system.

TABLE 19. VESSEL-OF-OPPORTUNITY SKIMMING SYSTEM (PRE-ADAPTED VESSEL)

Ratings vs. Scenarios		Sea State	Sea State 4		Sea State 5		Sea State 6	
Wt.	Factor	Oil Viscosity	Medium Crude 30 cs	Heavy Oil 5000 cs	Medium Crude 30 cs	Heavy Oil 5000 cs	Medium Crude 30 cs	Heavy Oil 5000 cs
0.30	Performance		.5	.5	.3	.3	.2	.2
0.15	Operational Control		.8	.8	.4	.4	0.0	0.0
0.15	Personnel		.8	.8	.6	.6	.4	.4
0.15	Mobilization & Setup		.8	.8	.6	.6	.5	.5
0.10	Support Logistics		.4	.4	.2	.2	.1	.1
0.05	Reliability		.7	.6	.4	.3	.3	.2
0.05	Long Term Environmental Effects		1.0	1.0	1.0	1.0	1.0	1.0
0.05	Survivability		.9	.9	.7	.7	.5	.5
		Totals	.64	.64	.42	.42	0.0	0.0

TABLE 20. VESSEL-OF-OPPORTUNITY SKIMMING SYSTEM (RANDOM VESSEL)

Ratings vs. Scenarios		Sea State	Sea State 4		Sea State 5		Sea State 5	
Wt.	Factor	Oil Viscosity	Medium Crude 30 cs	Heavy Oil 5000 cs	Medium Crude 30 cs	Heavy Oil 5000 cs	Medium Crude 30 cs	Heavy Oil 5000 cs
0.30	Performance		.4	.4	.3	.3	.2	.2
0.15	Operational Control		.7	.7	.4	.4	0.0	0.0
0.15	Personnel		.7	.7	.5	.5	.4	.4
0.15	Mobilization & Setup		.6	.6	.4	.4	.3	.3
0.10	Support Logistics		.3	.3	.2	.2	.05	.05
0.05	Reliability		.5	.4	.4	.3	.3	.2
0.05	Long Term Environmental Effects		1.0	1.0	1.0	1.0	1.0	1.0
0.05	Survivability		.8	.8	.6	.6	.4	.4
		Totals	.53	.53	.38	.37	0.0	0.0

Personnel: Because the crew of a random vessel of opportunity would not be familiar with the system or the methods of operations, they may cancel out some of the effectiveness of the skimmer system operating personnel. The personnel hazards may also be greater on a ship which was not designed for the task at hand.

Mobilization and Setup: The difficulty of locating and acquiring a suitable random vessel could reduce this rating area to near zero in the worst cases. The vessel must be suitable for adapting the skimmer system, and the time involved for this could be considerable. Setup would be affected by the sea conditions only if some setup was performed enroute in order to save time. With pre-adapted vessels, these operations should be smoother and less time consuming, due to the prearrangements.

Support Logistics: Depending upon the tank capacity of the support vessel, it would have to return to port or off-load the recovered oil into barges or other receivers. These problems are similar to the dedicated vessel approach.

Reliability: Reliability can be expected to be somewhat lower than for a dedicated skimmer because of the "jury rigging" that may have to be performed to install the equipment. Pre-adaption would help here. Otherwise, the reliability may be fairly good, and probably better than barrier systems, because of the fewer components involved.

Long-Term Environmental Effects: These would be minimal.

Survivability: The survivability of the system depends heavily upon the type of support vessel utilized, although pre-adapted vessels should rate somewhat higher than post-adapted vessels.

Time Considerations

A pre-adapted vessel of opportunity would minimize the time required to install a VOSS system, but because these vessels could have primary functions other than oil skimming, their limited availability could cause time problems in setup. Because several vessels could be pre-adapted, the chance of all of them being a considerable distance from the staging area at the same time would be reduced. However, the time to cease on-going primary operations

would probably be longer than for the dedicated skimmer case. If the support vessel was a small tankship the likelihood that procuring large receiving vessels could be in the critical path would be reduced. The key to this whole approach is the availability of the skimming vessels, which could be moved to remote locations by their operators for other tasks, unless contractual arrangements were made with the Coast Guard to keep them in the desired vicinity. An example time-line diagram for this system is shown in Appendix D.

Coast Guard Impacts

VOSS Impacts: The biggest problem with vessels of opportunity is the availability of the right vessels at the right time. This problem must be addressed at the Coast Guard Marine Safety Office or district level, once criteria for the vessel requirements are established. On the other hand, the most versatile VOSS skimmer is the one that is adaptable to the most vessels, so some considerations of vessel availability is necessary in designing the skimmer.

If WLB buoy tenders were utilized for support vessels, modification costs would be expected to be small, depending on the skimming system chosen. Installation of below-deck tankage or modification of the ballast tank would be the most costly items (also, tenders with these tanks installed would have reduced hold space for other applications). Special high capacity oil transfer pumps and piping should be installed for transferring stored oil to barges when installed tankage was full. Cleaning provisions, such as modifications to the tanks to permit Butterworthing, should also be installed. Towing provisions might have to be installed in order to off-load recovered oil into a barge while underway. The total weight of the tanks and stowed oil would be on the order of 42 tons. Installed tankage and pump costs could be on the order of \$20K to \$30K.

The Coast Guard could possibly obtain some of the MARAD vessels (tankers, etc.) for dedicated VOSS service or for other off-loading applications. Assignment of full-time crews would probably not be cost effective, but possibly the bulk of the crews could be provided by Coast Guard reserve personnel. For AOG tankers, crews of 9 - 10 officers and 20 - 40 enlisted men are probably necessary for full operations. Some of the vessels have

additional quarters that could be used to support other spill response personnel.

As discussed previously, several skimming concepts may be adequate, but a rope-type sorbent system appears to offer the best possibility for providing a wave-conforming, lightweight and flexible skimming system. This remains to be seen through development work, however. Siting and manning should offer few problems, as packaged systems should be relatively compact, easy to transport, and operable by only a few cross-trained personnel. A system would consist of two modules, one for each side of the vessel. Multiple systems should be stored at one point for outfitting more than one vessel, as oil skimming capacities of individual systems may be on the low side (100 to 150 gpm per module), depending on the design.

Development of a mop-type VOSS skimming system would probably require a limited-type development program, although a thorough analysis of the various configurations that could be used could involve a more extensive program. Because commercial equipment exists that could possibly be adapted to rope-mop systems, the development expenditures may be in the small to medium category, depending on the final system design. Commercially available rope-mop modules presently cost in the \$60K to \$70K range for the larger (100-150 gpm) units.

Other VOSS systems may need consideration if forthcoming tests on the mop concept do not show promise. The Sock concept will also be tested again in the near future, and significant improvements in that system may encourage further development. Recyclable-sorbent systems may also be feasible for VOSS applications. Development efforts on either of these alternative VOSS concepts could involve a limited to advanced development program, with probably a medium level of development expenditure.

<u>Related Development Areas</u>

Hose systems for transferring oil to receivers
Methods for receiver towing and transfer
Prearrangements for obtaining barges and support vessels
Vessel mounted slick surveillance system

5.5 Summary of the Rating Results for Skimming Systems

All systems drop in ratings as the sea state increases, with the differences between systems being magnified, if anything. In general, the barrier systems can be expected to be marginally effective in sea state 4, and ineffective in higher sea states. Well designed (large) direct-acting skimmer systems can be expected to be reasonably effective in sea state 4, marginal in sea state 5, and ineffective in sea state 6. In sea state 6, and possibly in sea state 5, the continuity of the slick may be insufficient to effectively skim, even if more effective skimming mechanisms were available. A summary of these scenarios is presented in Table 21.

The most attractive skimming concept for heavy weather use is the dedicated vessel system, followed by the pre-adapted VOSS approach. These systems appear to have the highest sea state operating potential, assuming that adequate skimming mechanisms and appropriate vessel sizes are utilized. At present, no direct-acting skimming systems like these are available, although they appear to be within the state-of-the art.

Of the barrier systems, the skimming-barrier concept appears to have the highest potential. However, all barrier systems have operational drawbacks in control, setup, reliability mobilization, survivability, and personnel considerations. Operation can be expected to be marginal in sea state 4.

Of the available skimming mechanisms, the one that appears to be most suitable for direct-acting skimmers is absorption into (or onto) a foam matrix; i.e., a sorbent system. To permit maximum conformance to the three-dimensional waves encountered in heavy seas, loose sorbent pads would be most effective, providing sorbent losses could be minimized (probably a much easier task with a catamaran-shaped dedicated skimmer than with a VOSS system).

TABLE 21 . SUMMARY OF RATINGS FOR REGIME 2 SKIMMING METHODS

Sea State	Sea State 4		Sea State 5		Sea State 6	
Oil Viscosity	Medium Crude 30 cs	Heavy Oil 5000 cs	Medium Crude 30 cs	Heavy Oil 5000 cs	Medium Crude 30 cs	Heavy Oil 5000 cs
Independent Skimmer and Barrier -- Distant Ship Support	.40	.43	0	0	0	0
Independent Skimmer and Barrier -- Close Ship Support	.45	.48	0	0	0	0
Skimming Barrier	.57	.55	0	0	0	0
Skimmer with herding barrier	.40	.40	0	0	0	0
Dedicated Skimmer	.74	.74	.47	.47	0	0
Pre-Adapted VOSS	.64	.64	.42	.42	0	0
Random VOSS	.53	.53	.38	.37	0	0

Next in order of decreasing surface conformance is the zero relative velocity (ZRV) sorbent rope, or "mop" concept, which permits two-dimensional conformance (vertical and athwartships for individual strands), followed by the ZRV sorbent belt concept, which permits one-dimensional (vertical) conformance. Various surface-piercing mechanisms are less desirable because they can create considerable turbulence and oil-water mixing, resulting in severe losses from the rather tenuous slick.

Where the slick can be thickened externally, as in barrier systems, a wider variety of mechanisms can be utilized, including the ones discussed above. The additional methods include oleophilic surfaces (disc skimmers), weir systems, and possibly inclined belts (sorbent and non-sorbent) and cyclone systems, as listed in what might be considered a decreasing order of preference for heavy weather applicability. Vortex generating systems are not considered applicable for these conditions.

A common problem in almost any of these systems is the need to have a large-volume receiving vessel standing by, in which to transfer the recovered oil.

5.6 Redistribution Systems

The following sections describe methods for in-situ slick burning, slick sinking and dispersing.

5.6.1 In-Situ Slick Burning

System Objective

To remove oil slicks from the sea surface by in-situ burning.

System Description

In order to successfully remove oil from the surface of the water by burning, two factors must be considered. A means of igniting the oil must be provided, and a means of heating the oil to its flash point (so that combustion can take place) and keeping the oil at this temperature, must also be provided.

An unconfined slick has been found to be very difficult to burn except for the brief period of time after a spill, when a very low viscosity, volatile pool of oil of significant thickness exists. As the slick spreads and weathers, burning becomes very difficult. Since safety considerations make burning of the slick near a stricken vessel generally unacceptable, means of burning a relatively thin and perhaps weathered slick are needed.

The most successful state-of-the-art burning technique under these conditions utilizes a wicking agent. The wicking agent serves to draw the low viscosity oil, after heating by surrounding oil flame or by the igniter, up away from the water, where it is somewhat insulated from the quenching action of seawater. A number of wicking agents have been tried, among them being straw, porous silica, porous ceramics, and a variety of buoy-type floating wicks. A typical test result from an application of an agent at 2 weight percent of the oil slick, yielded a residue of wicking agent and tarry solids comprising 15 weight percent of the slick. The residue, in most cases, must be collected upon completion of burning, thereby presenting an additional clean-up operation.

Some improvement in the rate of burning could conceivably be attained through the use of containment booms to thicken and concentrate the oil. The booms would prevent the breakup of the oil slick into several discrete pools and thus maintain the burning. The

thickening of the oil is necessary to insulate the combustion level from the cold seawater underneath. The use of booms would also feed oil into the area where wicking agents are present and the actual burning is taking place, which may be a small part of the total contained slick.

Three different approaches have been considered to contain burning oil. One approach is to use fireproof materials that will stand up to the heat. Another method is to utilize cooling sprays over the boom. The third is to use air or water jets to induce a surface current, which contains the oil.

The systems that have been investigated were developed for small spills with a short burn time and tested only in calm water. The water spray cooled boom appears to be the most suitable for offshore, large spill work because it is based on an offshore boom and the cooling system seems likely to prevent damage to the boom. The failure of the cooling system would cause the loss of the boom and pool of burning oil. The fireproof boom materials do not promise to have the strength or ability to operate offshore.

In extreme weather, even with wicking agents and a containment boom, high seas could disrupt the continuous flow of oil to the burn. Wave spray will rob heat from the combustion area. Water motion will disperse the oil in the water column or form an emulsion of the oil. The containment performance of the boom will also be degraded by the increasing sea state, as well as deployment and operational control of the towed configuration.

At this time the feasibility of high sea state slick burning appears low, even with the use of containment booms. The calm water burning difficulties, added to the problem of boom operation and rough conditions, offer little promise for a continuous and complete high volume burn in extreme weather.

<u>Ratings</u>

Ratings by scenario are presented in Table 22 .

<u>Performance</u>: For the sea states under consideration, burning efficiency cannot be expected to be very high. The initial oil viscosity will also have an effect, in that viscous oils may be difficult to impossible to ignite in the first place.

TABLE 22. IN-SITU SLICK BURNING

Ratings vs. Scenarios		Sea State	Sea State 4		Sea State 5		Sea State 6	
Wt.	Factor	Oil Viscosity	Medium Crude	Heavy Oil	Medium Crude	Heavy Oil	Medium Crude	Heavy Oil
0.30	Performance		.3	.1	.05	0	0	0
0.15	Operational Control		.5	.4	.2	.2	0	0
0.15	Personnel		.7	.7	.3	.3	.3	.3
0.15	Mobilization & Setup		.5	.5	.4	.4	.2	.2
0.10	Support Logistics		.8	.8	.8	.8	.8	.8
0.05	Reliability		.5	.4	.2	.1	0	0
0.05	Long Term Environmental Effects		.4	.5	.5	.5	.5	.5
0.05	Survivability		.9	.9	.8	.8	.7	.7
		Totals	.48	.33	.21	0	0	0

<u>Operational Control</u>: Control of the burning process, once it is started, is difficult. Variable winds and currents will make control even more difficult. The biggest problems will be in igniting, and in sustaining combustion so as to maximize the amount burned. Spreading of the wicking agents by vessel will be subject to problems similar to those encountered in spreading dispersant or sinking agents. Higher sea states will compound the control problem.

<u>Personnel</u>: Personnel problems will be similar to those encountered in dispersant and sinking systems, but will be made more hazardous because of dealing with an uncontrolled burning process at close range.

<u>Mobilization and Setup</u>: These problems will be similar to dispersant system setup problems. Special application devices must be installed on the vessels. Initial supplies of wicking agents and igniters must be mobilized. Although a relatively low wicking agent to oil ratio (by weight) is required, the low bulk density of the agent requires large volumes to be handled. Use of a confining boom would increase setup difficulties even more.

<u>Supply Logistics</u>: The high volume of wicking agent required, as well as a large number of igniters, results in a considerable logistics problem. Handling the wicking agent in solid (powder) form would be more difficult than handling a liquid.

<u>Reliability</u>: Equipment reliability problems would be similar to dispersant and boom systems. The reliability of the igniters is probably good, but the reliability of achieving slick ignition is lower, especially in higher sea states or with more viscous oils.

<u>Long-Term Environmental Effects</u>: As in other slick "redistribution" techniques, a considerable portion of the oil or oil product is left in the environment. In this case, the remaining material may be oil and tarry residue. Although the toxicity of this material is not known specifically, it is probably not degraded rapidly and could remain in the environment for a considerable time, unless skimming operations were undertaken to recover it. Considerable quantities of smoke would also be generated, which may be

tolerable in the open ocean but maybe not in near-shore areas where on-shore winds prevail.

Survivability: These considerations should be similar to those for similar systems where single, independent vessels are utilized. In general, high ratings are given, except if confining booms were utilized.

Coast Guard Impacts

The probability of developing a heavy-weather slick burning system in the near future does not appear to be high; the feasibility has not been demonstrated and efforts are not being made to pursue the heavy weather aspects of slick burning.

The advantages to the Coast Guard, if such a system could be developed, are that no high seas skimmer, receiving vessels, or oil disposal logistics problems would be involved. Disadvantages would be that a residue would be left over after burning, control of the boom and burning process might be difficult, the flaming slick would increase the operational hazard to response personnel and other vessels in the area, and the handling of wicking agents and igniters is required. Also, having to deal with any type of boom system in heavy weather is not desirable.

Development of a flame-resistant high seas boom system would probably involve a complete development effort, requiring a large to major development expenditure. Perhaps, maintaining contact with the present Canadian development efforts(17)(18) until something promising appears would be the best course of action for the Coast Guard at this time.

5.6.2 Oil Slick Sinking

System Objective

A material is added to the oil slick to increase its density so that the oil sinks below the surface and remains submerged indefinitely.

System Description

Many different substances have been used in an attempt to sink oil slicks[19]. Although treated sand has been found to be less efficient than chalk or asbestos, for example, it has the advantage of being readily available in large quantities, not only on the shore, but also on the sea bottom itself.

Estimates of the weight ratio of sinkant to oil for sinking vary from 1:1 to 8:1, with 4:1 as a realistic ratio for field work. If an oil spill rate of 1,000 gpm were to be dealt with, as described in the scenario, an average of sixteen tons of sinkant per minute would have to be applied at a 4:1 weight ratio. Some 23,000 tons of sinkant per day would have to be supplied to the operation.

The Sand Sink[20,21] method is a state-of-the-art system that uses sand dredged from the bottom as the sinking agent. The sand must be treated with a wetting agent so that it becomes oleophilic. Several types of wetting agents can be applied in aqueous solutions, and therefore the sand can be treated while in a sand/water slurry.

Large suction dredges, which have capacities of several thousand tons/hour of sand, often have hoppers to carry the spoil out to sea for disposal, and can be used to carry the sand to the spill site. The majority of these vessels are owned and operated by the U.S. Army Corps of Engineers. The largest of these dredges is 525 feet LOA, and would be capable of mining over 5,000 tons per hour according to estimates based on pump size and power. The size and speed of these vessels (15.5 knots loaded) would make them suitable platforms for transporting and spreading the sand. The largest of sea-going dredges can still be dredging in 10-12 foot waves.[22]

A system consisting of slurry spreader nozzles, mounted on pipe manifolds would have to be arranged on the dredge. The treated

sand slurry could be pumped from the hoppers by the dredge pumps and out through the spreaders. In this way the dredge also acts as the sinkant dispenser.

The slurry should impact on the oil slick with considerable force to insure mixing of the sand with the oil. Otherwise, the sand might rest on top of the oil pancake, cause it to sink and turn turtle, dumping the sand and returning to the surface. However, with lighter oils, below about 200 cs, the sand sinkant will pass through the slick without much effect. Therefore, light oil may have to be left to weather for awhile, so that the sinkant is more effective.

Ratings

Ratings are presented in Table 23.

Performance: Sinking methods are effective in getting rid of oil spills, but in time the oil may return to the surface in spite of the best efforts to sink it permanently. Even broken and dispersed oil slicks can be sunk, as long as the sinkant contacts the oil. Thus sea state may have only a secondary effect on sinking system efficiency, at least to the point where vessel handling and rolling limits the ability to function effectively (probably Sea States 6 & 7). More viscous oils should be easier to sink, partly because they hold the sand better, and partly because they tend to be more dense, and therefore, have less buoyancy to overcome.

Operational Control: Although several different operations must be performed by a single vessel (dredging, mixing, spreading), overall control problems should be minimal. As with dispersant systems, good surveillance is required to be able to direct the spreader vessel to the slick areas.

Personnel: Because of the large vessels involved, personnel discomfort and effort will not be great. Ratings are therefore fairly high.

Mobilization and Setup: Mobilization of dredges may be time-consuming, due to limited dredge availability. Because dredging is generally the type of activity that could be delayed during a

TABLE 23 . OIL SLICK SINKING

Ratings vs. Scenarios		Sea State	Sea State 4		Sea State 5		Sea State 6	
Wt.	Factor	Oil Viscosity	Medium Crude 30 cs	Heavy Oil 5000 cs	Medium Crude 30 cs	Heavy Oil 5000 cs	Medium Crude 30 cs	Heavy Oil 5000 cs
0.30	Performance		.5	.6	.3	.4	.1	.2
0.15	Operational Control		.7	.7	.3	.3	0	0
0.15	Personnel		.7	.7	.5	.5	.4	.4
0.15	Mobilization & Setup		.5	.5	.5	.5	.4	.4
0.10	Support Logistics		.6	.6	.4	.4	.1	.1
0.05	Reliability		.7	.8	.7	.7	.6	.6
0.05	Long Term Environmental Effects		.9	.9	.8	.8	.6	.6
0.05	Survivability		.9	.9	.8	.8	.6	.6
		Totals	.56	.60	.39	.42	0	0

period of emergency, and because most dredges are government owned and operated, the actual procurement of a dredge may not be a serious problem. However, the transit time to reach the supply base, and the subsequent outfitting for sand-spreading operations, could take considerable time. For these reasons, this category is rated fairly low. Another factor is obtaining the supply of wetting agent, but this may be of secondary significance if pre-arrangements have been made.

Supply Logistics: The time required for the barge to travel to a borrow area, fill its hoppers, and return to the spill, is one of the biggest logistics problems. To treat the scenario case of a 1,000-gpm spill, two large dredges could be required. Resupply of sand-additives is also a secondary problem, similar to that for resupplying dispersant (liquid transfer), but on a lower and/or less frequent scale. Higher sea states will slow these operations.

Reliability: The necessary equipment would probably be fairly rugged and reliable. In addition, all of the subsystems are accessible to operating personnel for repair and maintenance. The reliability of the sand in keeping the oil on the bottom is questionable, however.

Long-Term Environmental Effects: The long-term effect of an oil sinking operation is its weakest point. All of the oil may be immediately sunk, only to have a percentage of it percolate back to the surface over the following months. Even with a completely effective sinking operation, the oil may do more harm on the bottom than it would have done at the surface. The strongest argument against the use of sinkants is that they do not remove the oil from the ocean environment.

Several investigations of sunken oil show that it does not completely blanket the bottom, but rather settles in globules or strands. However, it is generally believed that this oil has an adverse effect on benthic organisms. Therefore, sinking should not be carried out in known shellfish harvest areas, or other areas where seafloor sensitivity is high.

The sunken oil is also subject to less biodegradation than oil at the surface. An oil slick at the surface is broken up and

dispersed by wave action, and is then more easily attacked by micro-organisms. Oil on the bottom tends to coagulate into larger globules and thus resist biodegradation. The decreased oxygen and light levels on the bottom will also slow down any biological activity. This effect will be most pronounced in areas where the sinking of oil is otherwise acceptable; i.e. in deep waters where there is little marine life to be affected by the oil.

Survivability: This system has a high survivability rating because of the large, independent vessels involved.

Coast Guard Impacts

At least one off-shore suction dredge has been outfitted for slick sinking service, and tested to demonstrate that the method was feasible (without oil).[20] Outfitting costs were on the order of \$150K and operational costs of the vessel were approximately \$11K per day (1971). The total cost of the wetting agent and alcohol mixture for sinking an entire 100,000-ton oil spill would be on the order of \$0.50M-\$1.0M, using today's costs.

The methods and end results are not likely to be improved upon significantly through further development. The potential damage to benthic organisms, and other long-term environmental effects, are perhaps the biggest objections to the method. Because much of the coastal zone where oil spills are likely to occur contains abundant and ecologically important benthos, the probability of using the method if it were available is low, particularly since other less damaging spill cleanup methods appear more promising.

5.6.3 Dispersant Systems - Vessel Applied

System Objective

To use chemical dispersants to remove oil from the water surface and suspend it as tiny droplets in the water column, thus reducing the wind drift, speeding the biodegradation of the oil, and lessening the tendency of the oil to stick to solids.

System Description

System components are:

1. A supply of self-mixing dispersant.

2. Spraying systems to apply the dispersant, including pumps, hoses, spray booms, and support hardware.

3. Support vessel, 160 feet or larger.

4. Surveillance system for directing spray boats to the slick.

5. System for dispersant storage, and for supplying spray boats with dispersant.

Dispersant: Self-mix dispersants, available in concentrated forms, have shown the most promise in recent years. These chemicals are oil soluble and are not solvent-based. They are sometimes applied with seawater to aid in their even distribution but are not pre-mixed with water. The required ratio of dispersant to oil volume depends on the application efficiency and many other factors but it generally ranges from greater than 1:10 for cold heavy oils to 1:50 for light oils. A 100,000 ton (30 million gallons) spill of heavy oil treated 1:10 would require approximately 10,000 tons (3 million gallons) of dispersant. This supply need not be located in one spot as it would be used over a period of days, allowing time for transport of additional chemical to the spill. However, to claim complete response capability by dispersion, this minimum quantity would have to be available from known sources.

Spraying System: Spray booms, approximately 15 feet long, are suspended over each side of the vessel with a supporting and

deploying framework. The spray booms can mount to the vessel's bow or amidships. With bow-mounted spray booms, the dispersant is delivered to the slick ahead of the bow wake so that some mixing will occur from this turbulence as well as from the propeller wash. Towed breaker-boards (pallets) are sometimes used to provide turbulence, also. Although modern dispersants are self-mixing, taking advantage of additional turbulence can be beneficial.

Diesel-driven pumps are used to pump seawater and self-mix dispersant through the nozzles in the spray booms. The seawater is used as a carrier for the dispersant to provide a high volume flow through the booms. This promotes a large droplet spray which is relatively unaffected by high winds, thus providing a uniform coverage. The spray boom height above the water can be readily adjusted for optimum spraying in various weather conditions. Figure 7 shows a typical arrangement.

A typical spraying system mounted on a vessel can spray a swath 60-feet wide at a speed of 8 knots, for a coverage of roughly 67 acres/hours. Units such as these are commercially available, but pumping capacities are limited.

Support Vessel: A vessel 160-feet or longer, capable of maneuvering in at least Sea State 4 to possibly State 6, is required. An open foredeck is desirable for mounting the spray booms. On board tankage for storing 36,000 gallons of dispersant would be desirable to permit at least 12 hours of continuous spraying at 50 gpm. If integral tankage is not available, open deck space for portable tanks would be needed. Deck tanks are more prone to cause stability problems and are thus less desirable. Minimum roll in heavy seas is desirable, as spray booms will extend from both sides of the vessel.

Many vessels would be more or less suitable for spraying operations, including buoy tenders, certain Navy ships, fishing vessels, and especially offshore supply boats. Modifications to the vessels to support the spray booms would be minimal, if any. Offshore supply boats, as discussed in section 5.4 , may have internal tankage already installed below decks, or tankage could be supported on the deck. A typical supply boat in the 160-200 foot range has on

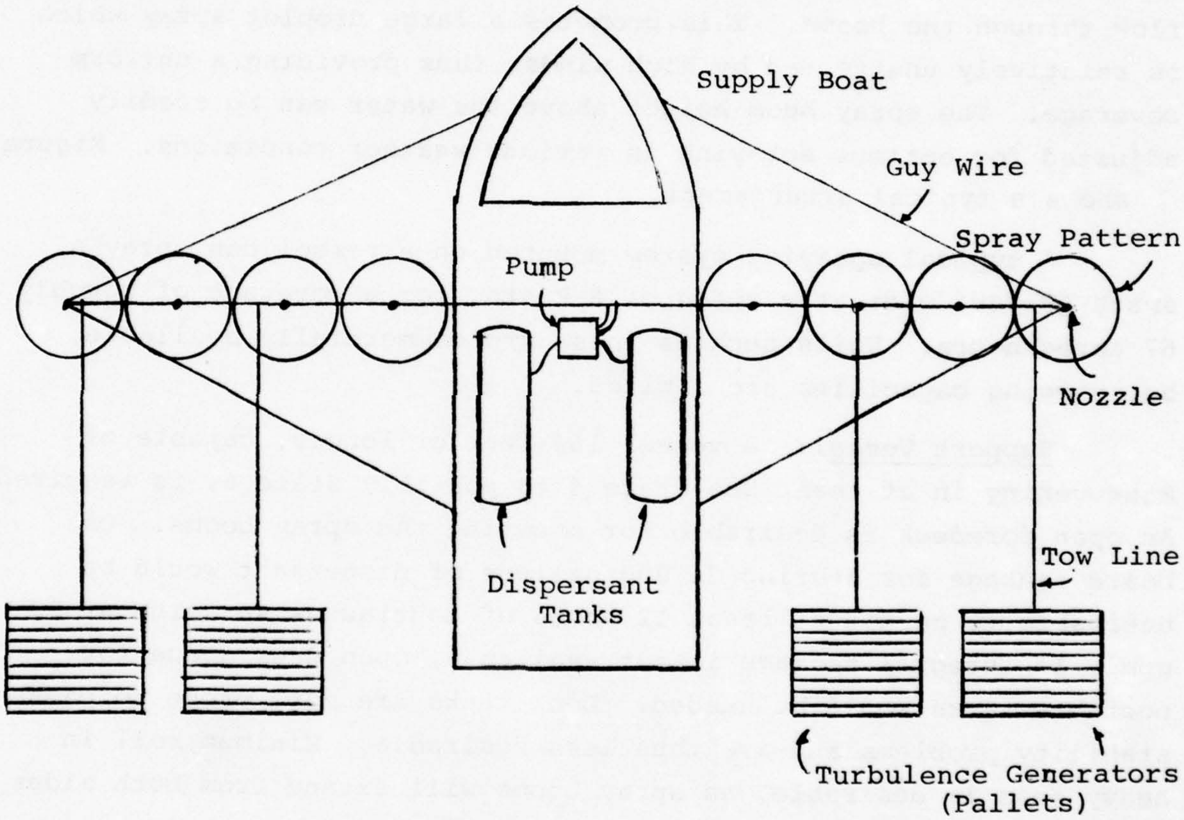


FIGURE 7. DISPERSANT SYSTEM - VESSEL APPROACH

the order of 800-1100 dwt capacity, which must be distributed between bunker fuel, rig fuel, ballast water, potable water, miscellaneous tankage, and deck and other cargo. The total volumetric capacity usually represents far more than the deadweight capacity of the ship, and therefore the actual cargo distribution must be carefully matched to the mission. Towing a small barge full of dispersant may be the easiest solution to the logistics problem for supply boats. Unfortunately, the availability of supply boats in areas such as the northeast U.S. is limited.

Surveillance System: Aircraft equipped with radio and visual detection gear will be useful in assigning courses to spray vessels (also to any other type of slick response device). Helicopters might be able to work from nearby ships.

Dispersant Storage and Supply System: Barges could be used to transport dispersant from the supply center storage to the staging area. If weather permits, dispersant could also be taken by barge directly to the spill site. The support barge should have pumps for loading dispersant onto the spray vessels. Barges could also be the normal containers for long-term bulk storage, as opposed to storing the material in field storage tanks and then transferring it to tank trucks or other containers when a spill occurs. The support barge could also be outfitted with spray booms and could then provide additional spray coverage during periods when the other spray vessels were not being resupplied with dispersant.

The alternative to using a barge is truck transport of material from field storage to dockside loading facilities at the staging areas. All vessels would then refill their tanks only at the dock. However, many vehicles would have to be put in service to maintain a high supply rate.

System Function

In order to respond to a spill, it is first necessary to locate supply boats or similar vessels and to direct them to the staging area near the spill. Simultaneously, the spraying systems that have been delivered to the staging area are readied for fitting on the vessels. A large volume of dispersant must be available at

the staging area for resupply or loaded onto a barge for bulk transport to the staging area. When the vessels arrive they are outfitted and their tanks filled with dispersant. Some dispersant may be stored in on-board tanks and the rest in portable deck tanks.

Once the vessels are on site, spraying begins, aided by aerial surveillance. It is important to start at the downwind end of the slick and to work the perimeter, coralling and reducing the size of the slick as the boats work toward the source.

Four vessels, each spraying 50 gpm of dispersant, could keep pace with a spill rate of 1000 gpm depending on the oil characteristics. This would allow a ratio of 1:10 dispersant to oil, which should be sufficient for a heavy oil. Each vessel should, therefore, carry enough for 12 hours of spraying, in order to limit the resupply frequency to once a day. The 50-gpm rate per vessel is twice that needed to disperse 1000 gpm of oil, but this would permit boats to work only half the day, say during 12 daylight hours. Average spraying rates of considerably less than 50 gpm should be anticipated, however, if thin slicks are to be treated. Otherwise, considerable wastage would occur, increasing operating costs (50 gpm dispersed over a 60-foot wide swath at 8 knots would treat a 0.4-mm slick at a 1:10 ratio--the 5-mm thick patches in the scenario would require several more passes, but the 0.03-mm wide-area slick would be treated at a dosage 13 times too high). Obviously, a way of quickly adjusting the dispersant rate and of determining what the slick thickness actually is, would be desirable. Otherwise, a rate suitable for the thin slick could be sprayed continuously, with the thicker patches requiring many more passes. Considerably more vessels would be required, also. While quantitative data on dispersion rate is not available, thin slicks are dispersed essentially on contact with the dispersant. Thicker oil takes longer but several hours has usually been sufficient time for all oil to disperse in most actual treated spills, as long as sufficient dispersant was present. If treated oil does reach the shore before it disperses, it has less tendency to stick to sand, rocks, etc., than untreated oil.[23] This means that a following tide may wash off much of a beach which has been contaminated with treated oil. This could possibly simplify

beach clean-up operations later on. Thus, an oil slick in danger of reaching the shore could possibly be sprayed with chemical dispersant to aid later clean-up operations, or to enhance natural weathering. Of course, the near-shore areas are usually the most environmentally sensitive, and the decision to add dispersant to the oil would have to be carefully weighed. Also, dispersed oil might sink into the wet sand, only to resurface later.

Ratings

Ratings are presented in Table 24.

Performance: Dispersion is one of the few spill treatment techniques where rougher water usually helps the situation. However, if the slick becomes naturally dispersed or broken up in heavy seas, effective contact between the dispersant and the oil may not be obtained. Thus in Sea State 6, performance of dispersants may decrease, although the oil may appear to have been thoroughly dispersed. Untreated oil will eventually rise to the surface again because of its natural buoyancy and larger droplet size (higher interfacial tension). The secondary slick resulting from this phenomenon may be of considerably smaller magnitude, however, as some oil degradation is bound to occur during the period of natural dispersion.

The more viscous oils may slow the rate of dispersion, but they should not reduce the dispersion effectiveness if the right treatment ratio is used. A heavier oil may hold together better in slick form in rougher seas than a light oil, but the heavy slick may be less uniform in thickness. In Sea State 4 the light oil may be easier to treat than heavy oil, because of more uniform thickness, but in Sea States 5 and 6, the two could be of equal difficulty. Estimating slick thickness and related dosage will be a major operational challenge.

Operational Control: Control problems are less than most other vessel-based systems. Single, independent vessels are utilized, and resupply of dispersant is relatively infrequent, hopefully limited to one transfer per day. Transfers could be made at the staging area, or possibly directly at the site from a resupply barge.

TABLE 24. DISPERSANT SYSTEMS (VESSEL APPLIED)

Ratings vs. Scenarios		Sea State	Sea State 4		Sea State 5		Sea State 6	
Wt.	Factor	Oil Viscosity	Medium Crude	Heavy Oil	Medium Crude	Heavy Oil	Medium Crude	Heavy Oil
0.30	Performance		.9	.9	.9	.9	.8	.8
0.15	Operational Control		.7	.7	.5	.5	.4	.4
0.15	Personnel		.7	.7	.6	.6	.4	.4
0.15	Mobilization & Setup		.6	.6	.5	.5	.4	.4
0.10	Support Logistics		.8	.7	.7	.6	.5*	.4*
0.05	Reliability		.8	.8	.7	.7	.5	.4
0.05	Long Term Environmental Effects		.6	.6	.6	.6	.5	.5
0.05	Survivability		.9	.9	.8	.8	.7	.7
		Totals	.76	.75	.68	.67	.53	.52

* Assumes vessels return to port for refilling.

Sea States 5 and 6 may present vessel problems, especially with roll. If roll is excessive, the spray booms extending from each side of the vessel's bow may be dipped into the water, causing non-uniform spraying and possible boom damage. If the vessel is limited to very low speed for safety in the severe weather, the spray coverage will be limited.

Personnel: Because of the large, independent vessels involved, operating personnel should generally have few problems, except during resupply operations. As in any operation on an oil slick, the ability to observe the slick is important, and higher sea states will generally limit this capability.

Mobilization and Setup: The most difficult problem will be in mobilizing the available supplies of dispersant from their various storage locations. If barges are used for bulk storage, then the barges can be towed directly to the staging area, or to the spill site. Other storage methods involve considerably more transfer steps (tank to trucks, etc.). The spray equipment is generally lightweight and portable, and setup on the vessels should be fairly easy. Obtaining the spraying vessels could be a problem, unless pre-arrangements were made. None of these problems should be a function of sea state or oil type.

Supply Logistics: Large quantities of material must be supplied to the spraying vessels on a continuous basis. However, the quantities included are perhaps an order of magnitude less than the oil recovery volumes handled with skimming systems. High sea states will make the transfers more difficult and time consuming. If the spraying vessels must return to the staging area to refill their tanks, even longer delays will result. The problems of making low speed liquid transfers in rough seas could be difficult.

Reliability: The spray system is simple in design and should have high reliability. The spray booms could fail if submerged in the sea by the vessel's rolling motion. Spare booms should be stocked in case this occurs. The damaged booms could be safely replaced at the staging area. The reliability of estimating the local slick thickness is questionable.

Long-Term Environmental Effects: As with any of the oil slick "redistribution" techniques, the oil remains in the environment until natural degradation processes remove it. In this case, an additional component, the dispersant, is also added to the environment, to be removed by similar natural processes. Depending on the local ecological conditions, concentrations, compositions, and other factors (currents, etc.), these materials may or may not be particularly damaging to the environment, when considering the long-term effects. This problem is under study at the present time, and is fraught with ecological as well as political considerations. A question related to this problem is whether natural dispersion in high seas states causes any less of a problem than the artificially enhanced dispersion resulting from the use of dispersing agents in lower sea states.

In general, the long-term effect category must be rated low at this time, until more light can be shed on the real effects of oil slick dispersion--either natural or artificial. Certainly, there are some relative benefits to artificial dispersion in that dispersed oil is not transported as fast as a slick (and is less hazardous to water fowl), treated oil has less tendency to stick to solid objects, and the smaller droplet sizes from artificial dispersion can be assimilated faster than naturally dispersed oil (under the right conditions). The lower toxicity of modern dispersant formulations must also be considered. Whether or not the oil viscisoty and density per se have any effect on the problem is not known; certainly the oil type could be expected to have some effect.

Survivability: The spray vessel should not have a survival problem as it can halt operations if the sea state is too severe. The spray system may experience failure if the booms are damaged by vessel roll. This may be repairable, and limited operation might continue even with damaged booms.

Time Considerations

An example time-line diagram for a vessel-applied dispersant system is shown in Appendix D. Once the OSC decides that dispersant use may be necessary, he must consult with the EPA and representatives of all concerned states. Following this

approval, pilot tests with dispersants must be made to determine a permissible rate of application.[24] The time required for this will probably result in the approval process lying on the critical path of a dispersant operation. As experience is gained, the approval process may be less of a bottleneck than anticipated at this time.

With the vessel systems, locating and outfitting vessels of opportunity for spraying service can lie on the critical path of the operations, although getting the dispersant to the staging area is also critical. The system upon which the ratings were based assumes that dispersant is stored in bulk on a barge, which can to be towed to the spill area to minimize the down-time required to resupply the spraying vessels during operations. However, unless a rapidly deployable land-transportable source of dispersant is also available, the initial filling time for the spraying vessels can be a controlling factor.

The on-site resupply of spraying vessels from bulk transport barges is a problem akin to transferring cargo from skimming vessels to barges. The frequency of transfers could be considerably less, depending on the application ratio (dispersant-to-oil), but the control and transfer problems would be similar. For this reason, application operations may be limited to less than Sea State 5, unless vessels returned to port for resupply.

Coast Guard Impacts

Vessel Impacts: Coast guard and other military vessels have little, if any, built-in storage volume for liquids other than fuel and water. Pillow tanks, hard tanks, or drums would have to be installed to provide any on-board storage. The effect of added storage capacity for Coast Guard vessels has been discussed under section (Skimming). For dispersant spraying, however, a longer operational time would be possible, depending on the dispersant-to-oil ratio required. For example, the 12,000 gallons of storage considered for skimming operations would provide approximately 4 hours of spraying at 50 gpm. Because 50 gpm of dispersant concentrate is a high rate for present-day dispersant systems, a lower average application rate may make the lower storage volumes more practical; however, more vessels will then be required to handle the same spill rate.

Alternatively, a small barge loaded with dispersant and equipped with spray booms could be towed by Coast Guard vessels. Probably the 210, with its 10,000-GT vessel towing capacity, would be among the better vessels for towing. The effects on the slick of the wake from the towing vessel, and of the large beam of the barge, would have to be investigated by testing. The spray booms could also be mounted on the towing vessel, with the dispersant pumped from the barge to the tow vessel through a hose. Barges would not be as maneuverable as desired for dealing with patchy oil, especially in heavy weather.

Aircraft Impacts: Aircraft will probably be required to provide surveillance of the slick during spraying operations.

<u>Siting</u>: To completely disperse 100,000 tons of oil, more than 10,000 tons of dispersant (2.7M gallons) could be required. Quantities of this magnitude must be on hand if dispersion is to be effective, because production rates could not supply the demand rate for a large spill. The siting problems are not unique to extreme weather situations, and are best addressed in a separate study. The important considerations and tradeoffs that must be taken into account should include the following:

1. Storage - bulk (in a few large field storage tanks at strategic locations, or in barges that can be readily towed to the spill site) or smaller containers (smaller storage tanks at several locations; drums; storage in tank-truck trailers ready for immediate delivery). Probably a combination of these storage types would provide the optimum system.

2. Transport mode from storage to the spill site - tank truck for shipping from field storage locations to dockside; tank car (rail); pipeline from field storage to nearby dock facilities; barge, from mooring site to debarking site, or direct to spill site. The problems in obtaining a sufficient number of transport vehicles on short notice must be addressed, because average supply rates of around 150,000 gallons per day would be required to disperse a 1,000-gpm spill.

3. Location of manufacturing facilities or blending plants for producing dispersants. If this is a variable, it would have impacts on distribution costs. Shipping rates for bulk transport of dispersant chemicals to potential storage locations are probably on the order of 10-15¢/gallon average.

4. Locations of highest spill potential where dispersants may be used.

5. Locations of pier facilities that can be used for loading dispersant vessels by truck or pipeline (loading facilities of a refinery or chemical plant could possibly be used in emergencies, if planned for ahead of time). Districts, MSO's etc. can probably provide this information.

Spray booms and auxiliary systems are easily transportable and should present no unusual siting problems. One type of system weighs 6,000 pounds (without portable storage tanks) and measures 300 ft^3 for shipping.[25]

Manning: No unusual manning requirements should result from the use of vessel-applied dispersants. Cross-training of response personnel will be necessary, however. Both MSO's and strike teams should be able to supply sufficient trained personnel. The spraying equipment is simple, as are the techniques for installing it and applying the dispersant. A certain degree of skill will help operators in achieving optimum application, but this can only be gained through experience. Probably two trained personnel per vessel would be required, with some assistance provided by unskilled labor.

Budgetary Requirements

A high rate spraying system, suitable for a single vessel (spray booms on both sides of the vessel) could cost in the order of \$70K-\$80K. Smaller units cost on the order of \$15K-\$20K per system. Maintenance costs would be minimal. Temporary tankage costs could range from very little (reusable 55-gallon drums) to \$6K or more for a 12,000-gallon pillow tank. Permanent tanks and pumps installed in a WLB could cost on the order of \$20K-\$30K for 10,000

The big cost is the dispersant itself. Present costs for self-mix dispersant concentrates are on the order of $8 per gallon. Costs for large volumes may not drop substantially (to possibly $7 per gallon) because, one manufacturer claims, the principal ingredients of the formulation are being produced in bulk now, and therefore the current costs already represent bulk-chemical costing. For extreme weather, where sufficient mixing energy may be available in situ, some of the non-self-mixing dispersants may be suitable, with costs in the range of $4 per gallon. More tests are needed to explore this possibility.

For handling a 100,000-ton spill, a usable inventory of at least 10,000 tons of dispersant would have to be maintained; this represents an investment cost of approximately $21M (at $7 per gallon). The field storage or barge storage facilities could add an additional $3M-$4M to that investment. For widely-spaced potential spill locations, such as the West, Gulf, and Northeast coasts, separate inventories may have to be maintained. The inventory in a given region could be spread out among several storage facilities.

Costs for developing a large-scale dispersant program would probably be in the small to medium category, exclusive of major equipment or dispersant procurements. Points that should be addressed in further development include:

1. Cost minimization by dispersant manufacturers.

2. Complete logistics studies to minimize inventories and costs while maximizing utility and response speed.

3. Study of full range of suitable vessels, down to specific vessels that could be called upon by the Captain-of-the-Port or related Coast Guard commands (MSO's, Strike Teams).

4. Examine existing dispersant equipment for modifications required for adapting to specific Coast Guard vessels.

5. Study methods for handling bulk dispersants at sea in heavy weather--include full-scale testing to determine feasibility of alternative methods.

6. Studies of optimum application methods and how to best control the application procedures, including rapid estimation of local slick thickness.

7. Streamline the procedure for approval of dispersant usage (EPA).

Related Development Areas

1. Slick surveillance systems.

2. Liquid transfer methods between vessels.

5.6.4 Dispersant Systems - Aircraft Applied

Objectives

The overall objectives are the same as vessel-applied dispersant systems, except to do it quicker without the problems of dealing with the air-water interface.

System Description

System components can include:

1. Bulk supplies of concentrated self-mix dispersant.

2. Multiple large aircraft with spraying pumps, booms, and tankage for dispersant.

3. Surveillance aircraft with oil detection equipment.

4. Dispersant storage and bulk transport system.

Self-Mix Dispersants: See vessel-applied systems. Self-mix dispersants are even more important in this case because no artificial turbulence can be applied. However, in high sea states, sufficient turbulence may be present naturally to adequately mix even non-self-mixing dispersants.

Aircraft Spray Systems: Large transport aircraft with high payload capacity and fast response capability are suited to aerial dispersant spraying. A significant number of large spray aircraft of this type exist. Many of these planes are surplus aircraft put into service primarily for agricultural use. These planes range in size from DC-4's with 2,000 gallon capacities to Super Constellations with 4,400 gallons of tankage. Many of these planes could be quickly converted from agricultural spraying to dispersant spraying. One semi-dedicated DC-4 dispersant spray plane is presently on call for pollution incidents.

Other suitable aircraft, not presently outfitted for spraying, could be considered as well. C-130's have the range and payload (45,000 lbs.) desirable for spraying. Four thousand gallons of dispersant plus pumps and other equipment could be carried by one plane. If they were prefitted for quick installation of spray equipment, the required pumps and portable tanks could be possibly loaded aboard on pallets and connected up while the spray booms were being mounted.

Use of the Modular Airborne Fire Fighting System (MAFFS) for aerial spraying of dispersants has been suggested by Hildebrand, Allen, and Ross[26]. The MAFFS is an existing liquid spray fire fighting system for installation in a variety of unmodified cargo aircraft. The system has been used in Air Force C-130's and in an Army CH-47 helicopter. Thus, installation of the system in Coast Guard C-130 aircraft seems possible.

The MAFFS is a pneumatically powered device. The modular unit is charged with fluid and pressurized on the ground. The entire system is loaded as cargo into the support aircraft. Spraying, through two large nozzles directed out the cargo door, is controlled by an operator in the cargo compartment or by the co-pilot. Two changes in the MAFFS are considered necessary to facilitate dispersant spraying. The delivery flow rates must be greatly reduced from those used with fire retardants (which are as high as 38,000 gpm). The second change would be a system for controlling the center-of-gravity in the airplane as the tanks empty. Work on this problem is presently being done through the U.S. Forest Service. Materials of construction also need investigation for compatibility with the dispersants.

Installation of the MAFFS can be done in approximately two hours. The system carries 2800 gallons when in a C-130 and weighs 10,500 lbs. empty. If proper ground support is available, only 10 minutes turnaround is needed to refill the system.

A typical commercial-type aircraft spraying system utilizes a DC-4 airplane, 100 feet of spray boom and a 400-gpm spray pump. Each plane sprays a 200-foot swath and carries 2,000 gallons of dispersant. They operate at an altitude of 50 to 100 feet and fly 170 mph, covering approximately 400 acres in 5 minutes. These pumping rates and areas provide an average dosage of 5 gallons/acre, which is sufficient for a slick of 0.05 mm thickness applied at a 1:10 dispersant-to-oil ratio.

Surveillance Aircraft and Systems: Surveillance operations may involve continuous visual spotting of oil from a small aircraft, or a general mapping of the oil slick, updated regularly with data from a larger aircraft carrying electronic and/or photographic detection gear.

Dispersant Storage and Transport: Large barges or field storage tanks could be used to store the bulk dispersant at the supply center. If a barge was used, it would also provide a direct although relatively slow, means for transporting the chemical to a point near the airport chosen for spraying operations. Tank trucks would be required to transport dispersant from the bulk storage container to the airfield from which the spraying operations are staged. Careful choice of an airfield should be made to minimize both the distance from the tankage to the airport and from the airport to the spill site.

System Function

In the event of a 1000-gpm oil spill, the aerial dispersant system discussed herein could function as follows. First, the spray planes would be contacted, prepared for operation, and flown to the chosen staging airfield. Surveillance aircraft would begin to survey the slick as soon as possible. Dispersant would be loaded onto several tank trucks and they would proceed to the airfield. The planes would be filled and depart for the spill scene. The trucks would then return to the storage site for more dispersant.

The spray planes could cover 400 acres in 5 minutes before exhausting their chemical supply. Usually, if a higher dosage is needed, multiple passes over the same area would be made. Determining whether a sufficient dosage had been applied is one of the major problems with this approach, and it may be some time after spraying before the results could be assessed. Assuming that a plane sprays, flies 50 miles to the airfield, refuels and takes on dispersant, returns to the spill in less than two hours, and works for 12 hours a day, 1000 gpm of oil could be treated with ten planes.

Ratings

The ratings are summarized in Table 25.

Performance: The performance outcome of aerial and vessel application of dispersants will be similar if the operations can be satisfactorily controlled. Aerial methods would be well suited to wide area coverage of thin slicks.

Operational Control: One of the main advantages to aerial methods is that the aircraft is not subjected to the wave conditions. However, the ability to navigate effectively and control the spray coverage under the direction of surveillance planes or vessels will determine the efficiency of the method. This will be complicated by the fact that the slick will be constantly moving because of the wind (a 20-knot wind could move the slick a mile during the period of a plane's turn-around time). The higher winds that accompany higher sea states will reduce the uniformity of the spray coverage, particularly if the planes must fly somewhat higher for safety purposes. Visibility reduction in adverse weather will cause further losses in efficiency, from both a delivery and surveillance standpoint.

Personnel: The personnel rating is high because no vessels are directly involved (except possibly surveillance vessels). Low-altitude flying in turbulence or in poor visibility could

TABLE 25 . DISPERSANT SYSTEMS (AIRCRAFT APPLIED)

Ratings vs. Scenarios		Sea State	Sea State 4		Sea State 5		Sea State 6	
Wt.	Factor	Oil Viscosity	Medium Crude 30 cs	Heavy Oil 5000 cs	Medium Crude 30 cs	Heavy Oil 5000 cs	Medium Crude 30 cs	Heavy Oil 5000 cs
0.30	Performance		.8	.8	.8	.8	.7	.7
0.15	Operational Control		.8	.8	.8	.8	.7	.7
0.15	Personnel		.9	.9	.9	.9	.9	.9
0.15	Mobilization & Setup		.8	.8	.8	.8	.8	.8
0.10	Support Ligistics		.7	.6	.7	.6	.7	.6
0.05	Reliability		.9	.9	.9	.9	.9	.9
0.05	Long Term Environmental Effects		.6	.6	.6	.6	.5	.5
0.05	Survivability		1.0	1.0	1.0	1.0	.9	.9
		Totals	.81	.79	.81	.79	.75	.74

cause some stress on pilots, but exposure time to this environment is relatively brief, and rest periods are frequent.

Mobilization and Setup: Mobilization of dedicated spraying planes could be fairly rapid, and possibly more rapid than mobilization of the bulk supplies of dispersant that are required to fill them. Where planes must be outfitted with spray booms, etc., considerably more time could be required than if a MAFFS-type system was used.

Support Logistics: Logistics problems are one of the big drawbacks to aircraft application of dispersants. Many planes and even more tank trucks would be required to support a large operation. Consolidating the bulk supplies of dispersant into the vicinity of the response operations would be necessary to minimize the flight time. In addition to dispersant, considerable aviation fuel would be required.

Reliability: The spray systems, aircraft, and dispersant transport means are all of reasonable reliability. While the system hardware is reliable, the method for providing uniform coverage with dispersant is of questionable reliability in extreme weather conditions. The redundancy provided by the use of multiple planes will provide enhanced reliability for the total system.

Long-Term Environmental Effects: Same considerations as for vessel-applied dispersants.

Survivability: The system rates high on survivability because the aircraft are not subject to wave actions, and they can quickly leave the spill site and postpone further operations if the weather deteriorates.

Time Considerations

With adequate planning, aerial-spray dispersant systems can have perhaps the quickest response time of any Regime 2 approach. Optimization of dispersant storage locations is required to minimize mobilization times for either aerial or vessel type dispersant systems. Equipment setup on aircraft could take longer than setup on vessels (spraying systems could possibly be air-lifted to a vessel), although MAFFS equipment could be quickly installed. Appendix D shows an example time-line diagram for this system.

Coast Guard Impacts:

Aircraft Impacts: The C-130 would probably be a suitable carrier for a MAFFS-type system, and few, if any, modifications to the aircraft would be required. Installing a spray boom system would involve aircraft modifications, however, and a thorough engineering study would be required to assess the feasibility. Based on Hildebrand's[26] estimates for C-130/MAFFS delivery, it would require on the order of $6M-$7M for aircraft and fuel costs alone to disperse a 100,000-ton spill. This includes a small spotter aircraft ($220/hr rental) and a C-130 (at $2,500/hr), but no ground personnel, support systems, or dispersant costs. The same study also showed that a smaller delivery aircraft (a Canadair CL-215) would cost roughly the same overall, even with greater operating hours.

Vessel Impacts: No appreciable impacts are foreseen.

Siting: The siting problems discussed under vessel applications are similar for aircraft in certain respects. Tank trucks will have to be used for resupplying the aircraft, and the distance they must travel will depend on the location of storage facilities. As an example, one tank truck carrying 4,000 gallons of dispersant would have to unload every 20 minutes (for 12 hours) to control a 1,000-gpm spill. If major storage was located 50 miles away, and turn-around time at each end was 1/2 hour, and travel time averaged 38 mph, 11 trucks would be required

to maintain the supply; if storage was 100 miles away, 19 trucks would be required. Other logistics considerations should be taken into account in the same type of studies recommended for vessel application of dispersants.

Manning: Cross-training of pilots will be required to learn dispersant techniques, if Coast Guard aircraft are utilized. Specially trained equipment operators would also be required to operate the spraying equipment. These could also be cross-trained aircraft personnel. If contractor aircraft are utilized, trained Coast Guard personnel must be available to coordinate operations.

Budgetary Requirements: A single MAFFS would cost on the order of $575K. As this unit is designed for water service, a study would be required to determine suitability for dispersant application. In conjunction with development of a dispersant version of the MAFFS there must be tests of spray uniformity, extreme weather performance, and aircraft stability during spraying. Wing-mounted spray boom systems for a C-130 may be even more expensive, after modifications to the aircraft are considered.

Other budgetary considerations will be similar to those addressed under vessel application of dispersants. Studying vessel and aircraft methods together would, in fact, be the best approach, since both methods could have their place in maximizing effectiveness while minimizing costs. Anticipated development expenditures, even with combined aircraft/vessels could still be in the small to medium category. Because treatment of massive oil spills with dispersants alone is very expensive, studies should include the cost effectiveness of integrating dispersant techniques with skimming techniques. The use of skimmers to recover the bulk of the oil, and dispersants to treat the remaining large-area thin slicks, may result in the lowest overall costs for a given effectiveness level.

Related Development Areas

Slick surveillance methods for guidance purposes.

5.7 Non-State of the Art Systems

Two additional systems were investigated, which are both considered beyond the state-of-the-art. These are discussed briefly below.

Non-reusable Sorbents for Slick Immobilization: A conceivable system for initial response to an oil spill would be the rapid distribution of a non-reuseable sorbent material onto the thick slick near the source of the spill. Such a system could reduce the thinning of the slick, and enable a more efficient pickup when recovery equipment could finally be deployed. Recovery vessels could pick up the oil-soaked sorbent by conventional sorbent recovery methods, squeeze the oil out and dispose of the spent sorbent.

The key to this concept is early response. Conceptually, large cargo aircraft would drop suitable quantities of sorbent onto the slick while it was still small. The planes could be in operations some time before surface craft.

Cotton wasties and polyurethane foam could both be used as sorbents. They have somewhat different characteristics but both absorb about 20 times their weight of oil. The cotton must be used at a density of roughly 0.1 lb/ft^3 while the foam is used at 2 lb/ft^3. Both of these densities are too low for efficient transport, especially in an aircraft. They can each be easily compressed to 10 lb/ft^3 for shipping but the cotton must be re-expanded with a machine, while the foam is self-expanding. Cotton wasties are inexpensive ($0.5M - $2.0M to absorb 100,000 tons of oil), but the difficulties in rapidly expanding them from their compressed state to a usuable 0.1 lb/ft^3 density make their use impractical for large, high-rate spills. On the other hand, polyurethane foam, which expands relatively rapidly to its usable density of 2 lb/ft^3, is very expensive ($40M to absorb 100,000 tons of oil). Treatment of an an entire spill with sorbents is unrealistic, but the costs for the total spill are presented for comparisons with other methods.

The impacts on Coast Guard vessels would probably be similar to those of VOSS systems. Handling spent sorbent would be a major problem, however. C-130 aircraft could possibly be used for spreading sorbent, but special spreading equipment would have to be developed. For planes to treat two days of spillage at 1000 gpm, one million pounds of sorbent would be needed; five C-130's carrying 40,000 pounds of sorbent per trip would each have to make five trips. Siting of sorbent storage areas would have to be at aircraft bases to ensure quick response, and specialized training would have to be given to sorbent system operating personnel. Development of a complete system would probably require an advanced or complete development-effort, involving a large development expenditure. The areas of high-rate distribution of the sorbents, compression and expansion methods for efficient sorbent transport, and disposal techniques for recovered sorbent material would have to be addressed. In general, the feasibility of this approach is doubtful.

Microbial Elimination of Oil Spills: A frequently discussed potential means of cleaning up spilled oil is the use of microbial agents. The chief attribute of this approach is that it is "natural" and therefore, should not result in environmental damage.

In both fresh water and salt water environments, naturally occurring bacteria feed on hydrocarbons, converting them into protoplasm and fatty acids. These products are then consumed by other organisms in the food chain. The hydrocarbons are eventually converted into carbon dioxide and water. The natural elimination of hydrocarbons is a slow process. The rate of conversion is affected by a number of variables, such as type of hydrocarbon, types and population of microorganisms present, temperature, oxygen concentration, and the availability of the necessary nutrients -- primarily nitrogen and phosphorus compounds.

In order to adapt the natural microbial conversion of oil to a practical oil spill clean-up tool, it is necessary to greatly accelerate the process. To this end, research is being done to develop microbes or microbe mixtures which have an appetite for a wide variety of oil types and which also have a relatively long "shelf life" in a dormant state[27,28].

The state-of-the-art of microbial biological agents for treating large oil spills is basically still in the laboratory stage, or, at best, the initial development stage. The one available commercial product, No-Scum[29], has been used to treat a very limited number of intentional spills in the marine environment. However, these consisted of only a few gallons of oil with a maximum slick thickness of 125 microns. No information is available on the effectiveness with larger oil volumes or greater slick thicknesses. The recommended application rate for No-Scum is 10 pounds per acre of 125-micron-thick slick, or about 25 pounds per ton of oil, a 1:80 ratio. At this application rate, 1,250 tons of treatment material would be required to treat a 100,000-ton spill solely by microbes.

The feasibility of the microbe response approach to massive spill cleanup will depend directly on the amount of available oxygen, since two or more pounds of oxygen is required to convert every pound of oil. In fresh water, re-aeration rates are about 40 pounds of oxygen per acre per day with a 6 knot wind[30]. Above 4 knots of wind speed, the exchange of gas between sea and air increase with the square of the wind velocity[31]. If this oxygen transfer rate relationship were to hold in wind speeds up to 30 knots, then the oxygen transfer would be 1000 pounds/acre/day. This would allow for the conversion of 350 to 500 pounds of oil/acre/day. At this rate it would require 2 to 3 days to convert the oil in a uniform 125-micron-thick slick, or less than a day to convert the 0.03-mm wide-area slick in the scenario. Thus, the oxygen availability will probably be a limiting factor in the oil conversion if adequate microorganisms and nutrients are supplied (natural nutrient levels are probably more limiting than

oxygen), particularly since the assumed oxygen transfer rate of 1000 pounds/acre/day is probably higher than can be expected on a continuing basis, even in extreme weather.

Based on current and projected material costs, the cost to treat a 100,000-ton spill would be on the order of $25M for the microbes alone. Assuming that the dry powder could be formulated into a sprayable liquid, conventional types of dispersant spraying systems (vessels, aircraft) could probably be utilized for applying the cultures, with similar operational costs and logistics problems. Long-term storage would be a unique problem to solve.

The efficiency of treating large, relatively thick slicks of a variety of oil types and under varying conditions is yet to be proven. Since actual response efforts would, no doubt, utilize a variety of techniques, the interrelationships between microbial agents and mechanical and chemical clean-up (dispersant) techniques would have to be investigated. For example, it may be possible to obtain enhanced performance by utilizing the dispersant to break the slick into small droplets with greater surface area for microbial activity. However, because of the natural limitations, such as oxygenation rates, etc., microbial methods will probably remain in the realm of relatively slow, secondary-type response methods, most useful in smaller spills where the oil is likely to remain in the water-environment (without beaching) for considerable periods.

Because of the preliminary nature of the development effort so far, total system development costs are difficult to define or categorize. A rather long program is likely, however, unless a higher level of funding is provided by an interested agency. For extreme weather situations the method may have applications, especially if coupled with dispersant programs, but it is not likely to be a panacea or a solution to the massive spill problem. The best course of action may be to await the outcome of on-going research before pursuing any development by the Coast Guard.

5.8 Summary of Rating Results for Regime 2 Systems

In this section the broader concepts for dealing with spilled oil are compared. The concepts considered include skimming, dispersion, sinking, and burning. The various skimming systems have been compared already, and the system with perhaps the best potential for effectiveness in heavy weather was determined to be the large dedicated vessel approach. This approach is used in the comparisons presented in this section.

Determination of a "best" approach to dealing with an oil slick is perhaps impossible in the general sense, because so much depends on the state of the slick (continuity and turbulence), and on the local ecological conditions. To merely "get rid of a slick" is one thing, but to minimize the overall effects of a slick is another. Where extremes in the slick or ecological conditions exist, one approach may be clearly preferable to another.

From the rating analysis, it appears that in general, dispersion methods are technically superior to other "redistribution" techniques, and slightly better than dedicated skimming systems. The apparent advantage over skimming systems is due mainly to simpler system requirements for applying dispersants, and less severe logistical problems at the spill site. Dispersants can involve considerably higher costs, however. In specific cases the desirability of one system over the other could change considerably. The conditions under which one system may be preferable to the other are listed below:

Advantage is with dispersants, where:

1. a thin, wide-area slick exists,

2. the slick covers an area where environmental risks are minimal (off-shore, good flushing action, favorable current, deep water),

3. conditions are too rough for vessel techniques, but aircraft application can be utilized.

Advantage is with dedicated skimmer, where:

1. a thick slick exists (near spill source, or in windrows),

2. the slick covers an area where environmental risks from dispersed oil are great.

In practice, the full range of slick and environmental conditions may exist within a single spill situation. Therefore, both techniques could be applicable on the same spill incident.

For the dispersant approach, a slight advantage exists for aircraft application, mainly because of the immunity of aircraft to the wave environment. Costs will be higher, however.

A summary of the comparative ratings is presented in Table 26 The dedicated skimming vessel ratings have been adjusted to reflect comparisons with the redistribution techniques rather than with other skimmers.

The time considerations can be summarized in Figure 8 which is based on critical-path-type diagrams constructed for three skimming systems and two dispersant systems. The time to outfit aircraft with dispersant spraying equipment could be shortened if a MAFFS-type apparatus was utilized, but mobilizing the bulk of the dispersant near the staging airfield could still be a major problem.

TABLE 26 . SUMMARY OF RATINGS FOR REGIME 2 RESPONSE SYSTEMS

Sea State	Sea State 4		Sea State 5		Sea State 6	
Oil Viscosity	Medium Crude 30 cs	Heavy Oil 5000 cs	Medium Crude 30 cs	Heavy Oil 5000 cs	Medium Crude 30 cs	Heavy Oil 5000 cs
Vessel Applied Dispersants	.76	.75	.68	.67	.53	.52
Aircraft Applied Dispersants	.81	.79	.81	.79	.75	.74
In-situ Slick Burning	.48	.33	.21	0	0	0
Sinking	.56	.60	.39	.42	0	0
Dedicated Skimming Vessel	.68	.68	.43	.43	0	0

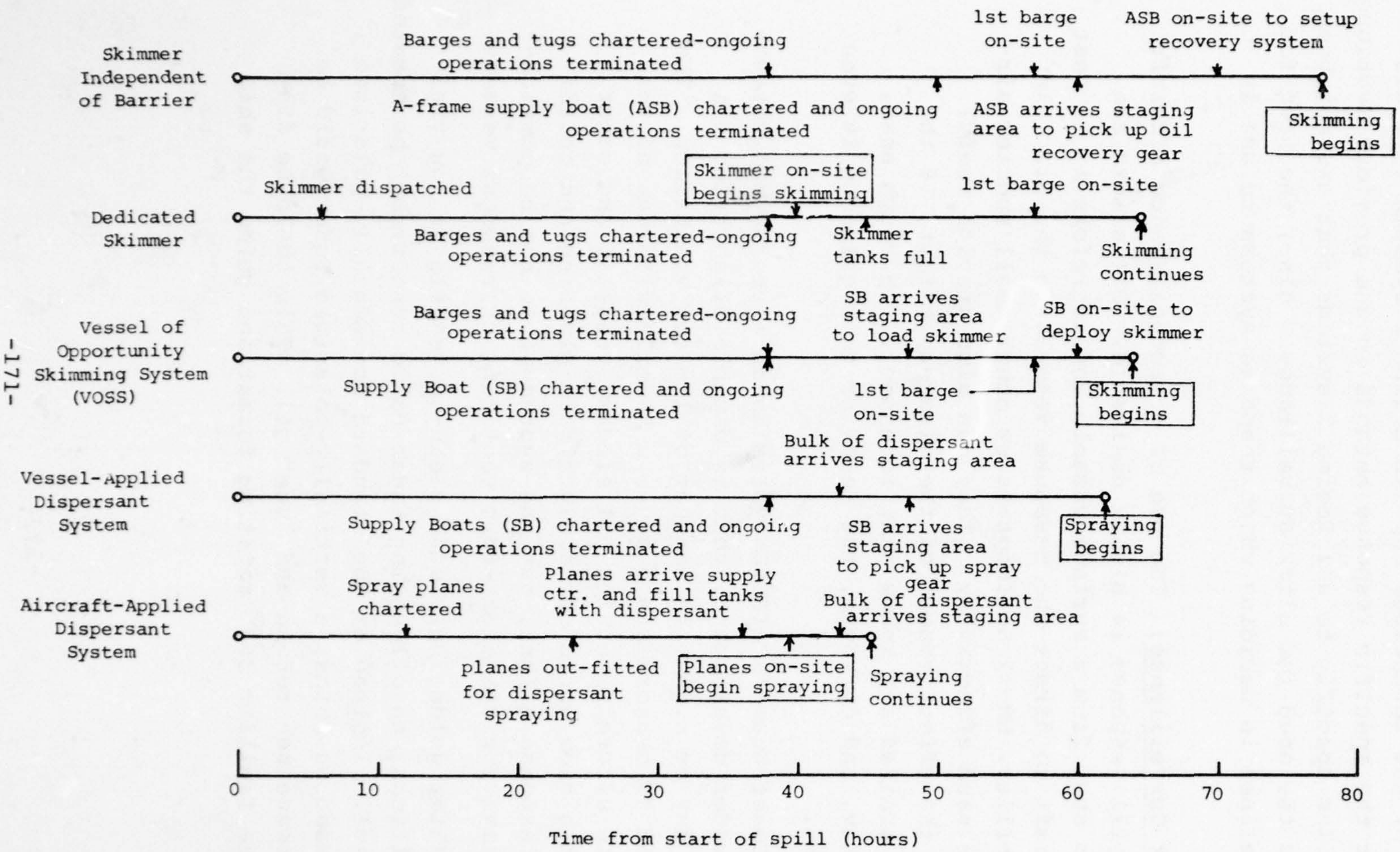


FIGURE 8 . SUMMARY OF PRINCIPAL TIME-LINE EVENTS

5.9 Discussion of Gaps Pertaining to Regime 2 Response Systems

Most of the technology gaps in Regime 2 systems were discussed under the specific response methods in the previous sections. The one problem specific to all Regime 2 systems that has not been discussed is the need for slick surveillance. Also, the need for better guidelines in deciding which response systems to use is discussed.

Slick Surveillance: The use of a reconnaissance aircraft in an oil spill response is highly desirable. Oil slicks are difficult to spot from a surface vessel, and therefore it is best to use aircraft to direct the response vessels to the oil. In normal visibility, HH-52 helicopters or other small spotter aircraft can be used effectively. They can also provide useful feedback on the effectiveness of the clean-up effort, if the observer is trained and knows what to expect. In rough seas, low visibility, and darkness, the need for this guidance is even more apparent.

The Coast Guard's AIREYE system is an airborne oil detecting system under development, that is capable of spotting oil and vessels day or night, in weather of limited visibility. The radar, IR and UV sensors can produce a 50-mile wide map of the sea below the aircraft showing oil slicks, vessels, and other marks. Such a view would certainly aid in planning and coordinating the response effort, but the system would not be particularly effective for the short-term vectoring of response vessels.

To better guide individual clean-up vessels in low visibility conditions, an oil-seeing radar could conceivably be mounted on each vessel. Instead of the standard horizontally-polarized radar beam used on ships, a vertically-polarized radar would be used to increase sea return and "see" oil. This could be displayed in the familiar 360° rotating format and guide the ship

to oil. These systems would allow the AIREYE to make less frequent over-flights.

The development and use of both an AIREYE data link to the surface ships and the individual ship's oil radar would probably improve oil spill response. Orderly clean-up operations might then be continued in darkness and fog, if other factors did not interfere (inter-vessel coordination, transfers, etc.).

One remaining area that needs addressing is in remotely estimating slick thicknesses and other slick properties. This information is important in determining dispersant dosages and in making decisions as to what approach to take for treatment (cleanup, dispersing, etc.). Presently, only actual sampling or in-situ measurements can provide this information. The microwave imager in the forerunner of the AIREYE system (the AOSS system) was capable of remotely determining slick thicknesses to a certain degree, but was not included in the AIREYE package.

A radar-based vessel-mounted slick tracking system could probably be designed in a limited development effort with a small to medium development expenditure. Existing technology could be utilized.

Guidelines for Response System Decisions: One of the major concerns for Regime 2 is whether to skim the oil or apply dispersants. To make decisions such as these, guidelines must be developed that can be used by the on-scene commander. In many cases, both operations may be applicable to the same spill, particularly a major one. Information on regulations, environmental concerns, sea state limitations, equipment availability, etc., must be considered in deciding which areas to treat with what method, and even when to do nothing at all. Costs cannot be ignored, either.

A climate must be established where qualified dispersants can be utilized when necessary without the time-consuming legal and procedural roadblocks to prevent rapid utilization. This does not infer usage without careful consideration of the long-term environmental risks, but these factors must be assessed quickly so that a timely decision can be made. This may involve pre-surveys of high potential spill areas so that guidelines to proper utilization of dispersants will exist when the need arises.

6.0 GENERAL CONSIDERATIONS FOR BOTH REGIMES

Several problem areas or technology gaps exist in response systems for both regimes. These are discussed in the following sections.

Towing Systems: Many systems require towing and support vessels that can tow at speeds as low as one knot in heavy weather. For this reason, a twin-screw, controlled-pitch (CP) propeller vessel, preferably with thrusters at the bow and stern, is desirable to accomplish this. Such vessels are not common in the U.S. in areas where heavy weather is prevalent, and, therefore, would have to be constructed, or else prearrangements should be made to obtain the ones that are available when the need arises. Use of such a vessel is imperative for work next to a barrier, where extreme maneuverability is required to prevent damage. A vessel length of 160 feet or more is considered necessary.

WLB buoy tenders have diesel-electric power plants, and therefore should have reasonably good low speed (one knot or less) towing capabilities. However, because of their single screw propulsion units, bow thrusters are probably necessary to ensure adequate low speed sea-keeping and steerage in heavy weather. Twelve WLB's presently have tunnel-type bow thrusters. Costs to install a 200-hp thruster are estimated at $110K. Towing equipment may have to be added (bitts, fair-leads, etc.). A 210-foot WMEC has a CP propeller, which would aid low speed operation, but it has no bow thruster. Twin screws will help its maneuvering capability, however. It has the capability for towing vessels of up to 10,000 gross tons capacity.

Navy ATF's (Cherokee class), ARS's and ASR's (Chanticleer class) have diesel-electric power plants, but only the ARS's have twin screws. Bow thrusters do not appear to have been installed on any of these vessels. Several types of commercial vessels, such as off-shore supply/tug boats and certain trawlers, have low speed towing capabilities and good maneuverability in heavy seas. Unfortunately, most of the tug/supply boats are in oil field service in places like the North Sea where severe weather conditions

predominate. The procurement of Navy or commercial towing vessels on a short notice remains a problem for the Coast Guard to solve.

Delivery Systems:

Helicopters: Coast Guard helicopters are suitable for relatively small loads, and for personnel transfers and surveillance tasks. Non-Coast Guard helicopters are available that will handle payloads on the order of 20,000 pounds, and should be borrowed, if necessary. Both the Army and Navy can probably be depended upon for this support in the few instances where it would be required. A few high-capacity commercial helicopters are also available, but special arrangements would have to be made to obtain them.

Vessels: Although 180-foot buoy tenders can carry loads of 50 tons on a deck area of 1,400 square feet, the ability to launch and retrieve large and bulky loads in heavy weather using the 20-ton crane would be difficult and unsafe. A better vessel would be a 160-foot or larger offshore supply boat with an open stern (roller desirable) and supplemental lifting capacity (A-frame or crane). Unfortunately, in the northeast U.S., where heavy weather spills are most likely to occur, offshore supply boats are not common. A-frame or other integral handling facilities on supply boats are even less common, but can usually be installed given sufficient lead time (unsatisfactory for spill operations). A portable crane could be driven onto the deck of a supply boat, but dock facilities do not normally exist that would permit this.

One alternative is for the Coast Guard to purchase similar vessels and utilize them in multimission functions, similar to the case for the dedicated skimmers described previously. Current purchase costs for offshore supply boats are in the order of \$2.5M - \$3.5M. Operating crews are in the order of 6 to 12 people and costs are probably in the order of \$2,000 to \$2,500 per day, exclusive of fuel and lube, depreciation, and profits. A vessel such as this could also be used for operating VOSS-type skimmers, applying dispersants, limited towing and salvage operating, fire-fighting, etc. Another alternative may be for the government to own such vessels, and contract the operation to commercial operators with the understanding

that spill control missions have priority. This would be similar to the approach the Navy takes with some of their salvage vessels. Barges, if specially outfitted, could also be utilized for transporting and launching heavy equipment.

Another type of delivery vehicle is the fast delivery sled (FDS), developed by the Coast Guard. This vehicle was designed for state 3 seas, and would be of limited use in the sea states under consideration here. The main difficulty with this concept is that final assembly or deployment must usually be made in the water, with the aid of swimmers--a difficult and risky task in high sea states. High speed towing by helicopter is feasible in relatively calm seas, but not in rough seas with present Coast Guard helicopters.

Temporary Oil Storage: When oil is off-loaded or recovered, a vessel to contain and transport the oil is required. Whether small tankers or oil barges are used, the availability of these vessels will determine the rate of operations. If no vessels can be found, operations will be severely impeded. Because of the slow speed of barges, on-call contracts with companies may be required to guarantee vessel availability in a given period of time. A current inventory of suitable vessels and their locations would also be a useful reference for finding additional support vessels.

To circumvent the problem of leasing barges on short notice, the Coast Guard could consider purchasing barges for deployment in strategic areas. A 90,000-bbl. barge may cost on the order of \$2.7M to \$3.5M, and a 50,000-bbl. barge on the order of \$1.5M to \$1.9M. (A 6,900-bbl towable bladder costs approximately \$250K.) Operation and maintenance of government owned barges could be contracted out. For comparison purposes, a 50,000-bbl. barge and tug can be chartered for approximately \$5K per day, and a 90,000-bbl. barge for around \$8K per day.

Dedicated barges could be provided with multi-use capabilities. For example, the functions listed below could be considered:

1. Recovered oil storage.
2. Bulk dispersant storage.

3. Oil-water separation (special piping to utilize internal tanks for separation, or individual separators)

4. High-volume flaring.

5. Dispersant spreading.

6. Launch and lifting provisions for deploying large oil-spill equipment items (boom, skimmers, etc.)

7. Fire fighting.

8. Securing facilities for off-loading cargo from stranded tankers.

9. Storage of floating-hose reels, and additional portable pump systems (ADAPTS).

10. Helicopter landing facilities (part of a false deck, which could support other activities).

The costs for these additional capabilities would vary according to the system, but only a limited development effort might be required because of the off-the-shelf nature of most of the components.

A barge requires a vessel to tow it, and vessel availability could be a problem even if the barge is not. Tugs normally used for towing a 50,000-bbl. barge are on the order of 2,400 hp, and for a 90,000-bbl. barge the power is around 3,200 hp. Some Coast Guard vessels may have this towing capability (the 210-foot WMEC, for example), but dependence on commercial operators may still be required. Costs of commercial-type tug/supply boats were discussed in the previous section.

The use of small self-propelled tankships would avoid the problems of towing barges, and could support many of the other functions listed above. The availability of small Navy tankers was discussed in section 5.4 (VOSS systems).

Because of the generally slow response of oil receiving vessels, other forms of temporary oil storage would be helpful in expediting the start of off-loading or recovery operations. Unfortunately, no other systems stand out as being particularly desirable

for heavy-weather, high-capacity storage. Pillow tanks and rubber bladder type containers are portable and quickly deployable, but they have limited capacities. Two alternative concepts which were considered are submerged reinforced-rubber domes and circular oil booms. Both of these concepts are impractical because of low storage capacities and/or difficult set-up and handling problems.

Liquid Transfers between Vessels: These procedures are key operations in a number of the evaluated response systems, including oil skimming, dispersant resupply, and off-loading.

When two vessels perform a fendered transfer operation, either underway or stationery, they are held closely together. The high seas during extreme weather cause large relative motions between the fendered vessels, making this type of transfer operation particularly hazardous. Systems allowing more distance between vessels would be desirable.

The Navy has developed techniques for refueling ships underway, utilizing side-by-side transfers through a hose suspended from a cable stretched between the ships. These operations can be performed in 8 to 10-foot seas at low speeds, or at higher speeds (6 to 10 knots) in calm seas. For transfers to or from a non-self propelled barge, a good method may be for the powered ship to take the barge in tow, and transfer the cargo through a floating hose running between the ships. This operation would be restricted to low speeds, and sufficient tow line and hose would be required to minimize the effects of relative surge or other motions. This approach could also be used for transfers between two powered vessels, if the aft vessel reduced power to permit towing by the forward vessel.

For securing a lightering vessel to a stranded tanker for off-loading operations, the method described in section 4.3 would probably be most successful. Again, a floating hose would be desirable, particularly if a large-diameter heavy hose is required.

Transfer Hose: A variety of hose systems can be considered for transfers between vessels, although a floating hose appears more suitable for extreme weather than a suspended or a non-floating hose.

Floats can be attached to any conventional hose to make it float. As long as the hose has suitable structural integrity for high-seas use this system will work, but handling may be a problem. It may be difficult to store the hose with floats attached. The floats are also subject to damage during handling and deployment.

State-of-the-art offshore floating hoses are designed to be highly durable, and thus suitable for extreme weather use. They are both bulky and heavy (for example: a 6-inch I.D. hose weighs typically 20 lb/ft. empty and 30 lb/ft. full of oil) and cannot be handled by men without mechanical assistance. Four hundred feet of a typical 6-inch I.D. floating hose could be spooled on an 11-ft.-O.D. reel, 10 feet long. Floating hose is commercially available for on the order of $75 per foot for 6-inch hose, or $120 per foot for 10-inch hose. Handling systems and reels would have to be developed.

Pneumatically-buoyed floating hose (double jacketed) is available, but for Coast Guard applications special designs would probably have to be developed. One concept is to install a 6-inch folding ADAPTS hose inside a similarly-constructed 10-inch hose, and inflating the annulus. Such a hose arrangement would weigh only 5,8 lb/ft empty and 16.5 lb/ft full of oil. Clearly a hose of this design would have handling advantages over comparably sized commercial floating hose. The prime drawback to this lightweight hose would be its limited durability and low working pressure (75 psi), which limits its flow handling capabilities. However, other configurations could be investigated. A relatively small development effort would be anticipated to develop such a system.

Flaring Methods: In section 4.3 flaring was discussed as a means of continuously disposing of off-loaded oil. The relatively low burning rate of conventional off-shore burning apparatus was cited as being one of the limitations of this approach. It is possible that present technology can be utilized in scaled-up flaring systems to achieve burning rates of 100,000 barrels per day or more. There are, however, several features that could be incorporated into the up-dated systems that would improve the usability, by reducing the power requirements and weight of the systems.

One feature would attempt to utilize the vast amount of energy released to power the oil and water pumps and air compressors. Another feature would use some of the heat released to increase the fluidity of the oil, which in some cases would otherwise be too viscous to pump. It appears that the generation of moderate pressure steam could aid in accomplishing both goals. The steam could power the air, water and oil pumps and also be discharged adjacent to the oil intake pipes to heat the oil. It is possible that simpler and more efficient means for atomization can be utilized, such as mechanical impact using high speed rotors. The large volumes of air required in the system could conceivably be provided by conventional chimney effects using the intense heating in an indirect but simple manner, as indicated in Figure 9 . Such a flare might be permanently erected on the deck of a low response platform or a barge. It could then be dispatched to the stranded vessel and moored nearby. A barge-mounted system could also be used for continuous flaring of recovered oil-water mixtures from oil recovery operations.

Another conceivable flare arrangement which could offer faster response is a towed flare as shown in Figure 10. This flare would be self-deploying and would only need mooring to the stranded vessel or a nearby platform and hook-up to the oil pumps. The spar-like shape of the flare would help minimize wave induced motions. This type of flare might still utilize conventional burner technology, but the structural and motion characteristics would need investigation. This would probably require a complete development effort for the overall system, while utilizing existing burner technology. A medium to large development expenditure would be anticipated, depending on the size and complexity of the final system.

A deck-mounted ducted vertical burner system with integral steam coils, would require the most development of all because of its conceptual nature at this time. Probably a medium to large development expenditure would be involved, with a complete development effort.

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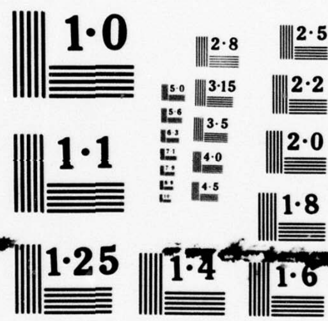
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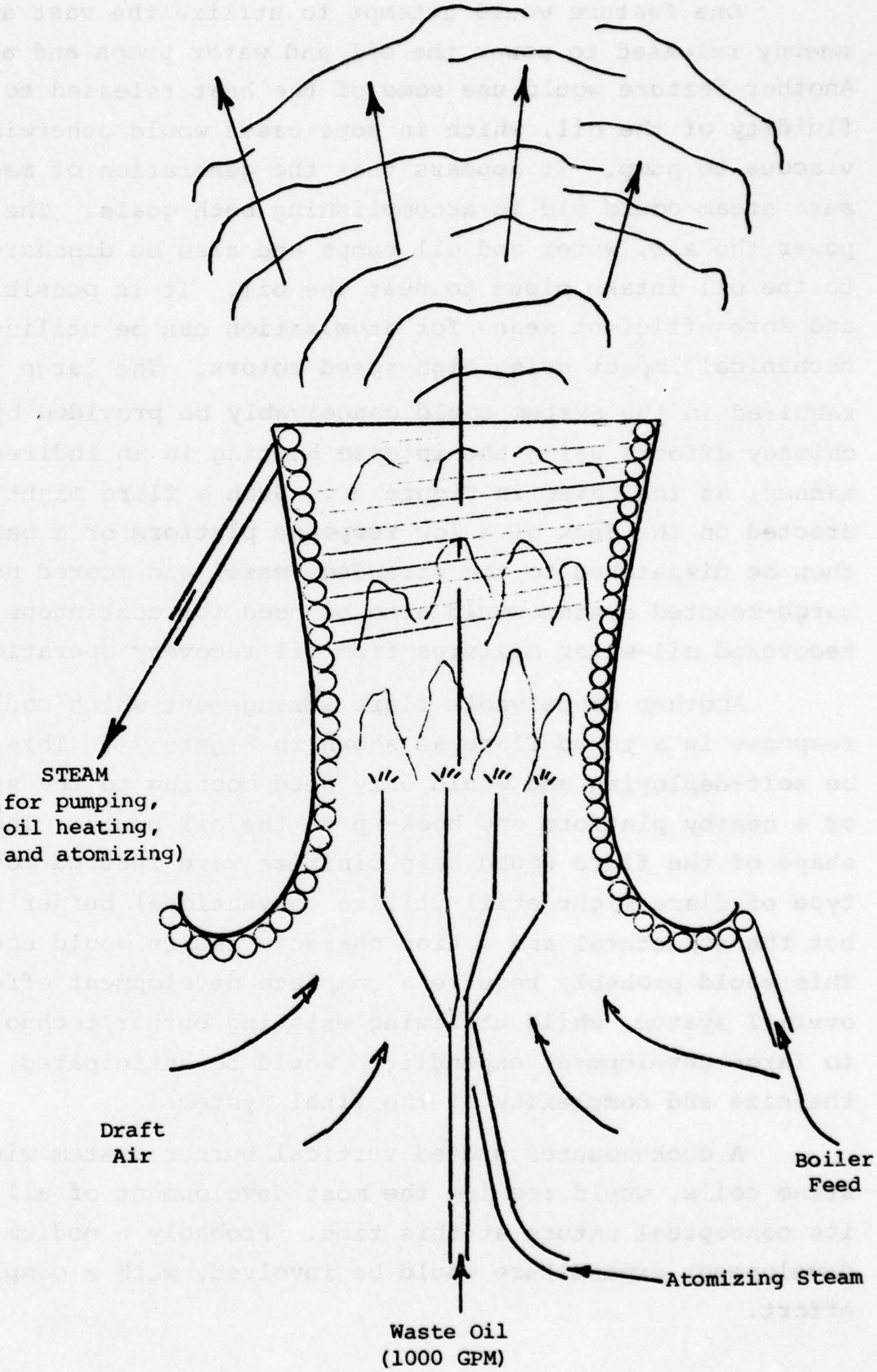

FIGURE 9. STEAM GENERATING FLARE

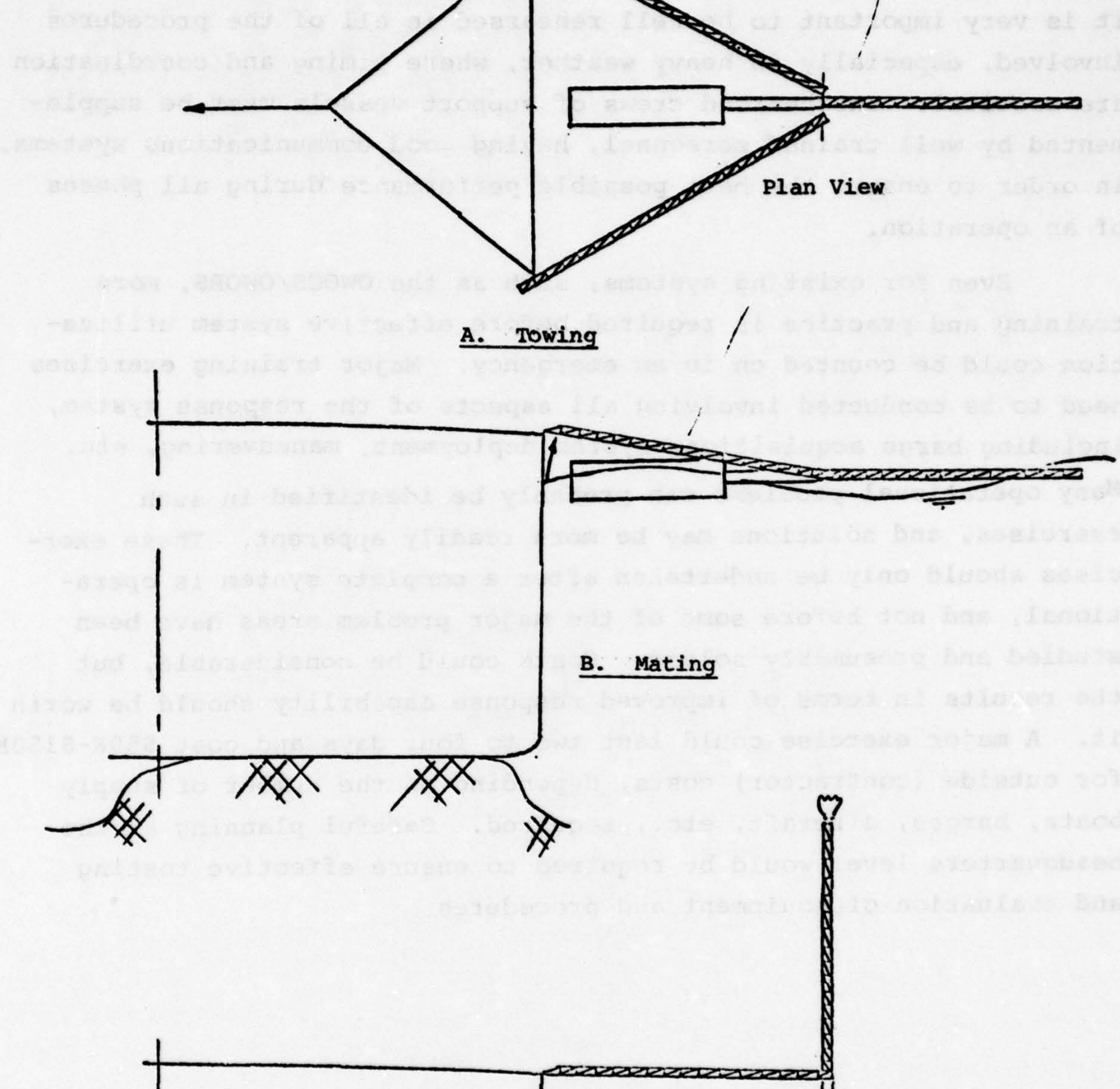

FIGURE 10. HIGH SEAS FLARE CONCEPT

<u>Training Needs</u>: Because of the complicated processes that are required to prepare and launch many barrier/skimmer systems, it is very important to be well rehearsed in all of the procedures involved, especially in heavy weather, where timing and coordination are critical. Unrehearsed crews of support vessels must be supplemented by well trained personnel, having good communications systems, in order to ensure the best possible performance during all phases of an operation.

Even for existing systems, such as the OWOCS/OWORS, more training and practice is required before effective system utilization could be counted on in an emergency. Major training exercises need to be conducted involving all aspects of the response system, including barge acquisition, system deployment, maneuvering, etc. Many operational problems can probably be identified in such exercises, and solutions may be more readily apparent. These exercises should only be undertaken after a complete system is operational, and not before some of the major problem areas have been studied and presumably solved. Costs could be considerable, but the results in terms of improved response capability should be worth it. A major exercise could last two to four days and cost $50K-$150K for outside (contractor) costs, depending on the number of supply boats, barges, aircraft, etc., required. Careful planning at the headquarters level would be required to ensure effective testing and evaluation of equipment and procedures.

7.0 CONCLUSIONS

The major conclusions resulting from the study are presented in this section. Minor conclusions and findings specific to individual response systems are given in the response system evaluation summaries, in Appendix B.

1. Development of a limited extreme weather oil pollution response capability appears to be feasible, using techniques or concepts that are currently within the state-of-the-art. However, in all cases there are either functional, administrative, or hardware limitations that must be overcome in order to realize this capability. Development of the maximum capability could take up to eight years or more, but definite improvements could possibly be implemented within two to three years. This assessment is based on the following considerations:

Regime 1: Where a tanker stranding could result in breakup and spillage of the entire cargo, immediate jettisoning using the ship's pumps appears to offer the best chance of saving the ship and containing the bulk of the cargo, although some spillage must be tolerated. Ballasting-down and other rapid stabilization techniques offers the next best possibility for preserving the ship until salvage operations can be undertaken. With the use of portable pumping systems for off-loading cargo into receivers or flaring systems, no dramatic increases over present response speed or pumping rates are expected, although improvements can be made. Ship bombing or similar "last-resort" techniques are not likely to offer any improvements over conventional off-loading approaches.

Regime 2: When a spill occurs, dispersant application and/or skimming, using large (over 160 feet long), dedicated, sorbent-type skimmers, appears to offer the best chance for cleanup success. Skimmers would probably be better for thick slicks (1-5 mm) and dispersants (aircraft or vessel applied) would be better for thin slicks mainly because of efficiency differences and treatment cost considerations (dispersants are relatively expensive). However, dedicated skimmers

would probably be effective only up to sea state 5, whereas dispersants could be applied by aircraft in sea state 6 (beyond sea state 6, a slick is not likely to exist). Vessel-of-opportunity (VOSS) skimming systems would probably not be as effective as large, dedicated skimmers, but some types may offer improvements over existing skimming systems, and are closer to the hardware stage. None of the above skimming devices exists in a usable form at this time. The best of the existing skimming systems is probably the Coast Guard skimming barrier, which is expected to be only marginally effective in sea state 4.

Skimming concepts that do not appear to be suitable for extreme weather deployment include all barrier-dependent systems (except the skimming barrier), and all of the small, independent skimmers that exist now. Slick burning or sinking methods also appear infeasible or undesirable at this time.

2. Keys to rapid and effective responses in all extreme weather situations include: rapid and accurate assessment of the situation, the ability to take immediate control, having the authority and the knowledge to pursue the best course of action without time-consuming regulatory constraints, having on hand all of the government and private resources necessary to accomplish the objectives, and the ability to mobilize these resources quickly. At the present time, all of these areas need improvement.

3. Each element of a response operation is important in determining the success of the response, including component interaction and performance, overall operational control, personnel, mobilization and setup, support logistics, reliability, long-term environmental effects, and survivability. All types of interactions between the oil, water, atmosphere, personnel and response equipment (vessels, aircraft, machinery, and supplies) must be considered to ensure that a dependable and functional system will result.

8.0 RECOMMENDATIONS

The recommendations presented in this report are based on the technical feasibility, costs, and impacts on the Coast Guard of the major systems and system variations that might be considered for use in extreme weather pollution response operations. These recommendations are intended to provide guidance to the Coast Guard on the best general extreme weather pollution response approaches to pursue. Other suggestions for minor studies have been made throughout the report, and are not included here. The order of presentation generally represents a priority ranking of the recommendations, although in many cases parallel development efforts should be conducted.

Regime 1

1. The adoption of cargo jettisoning as a planned initial response technique for tanker strandings should be undertaken. This will involve solving administrative, legal, and similar problems, and in particular the problem of educating the public on the merits of jettisoning as a way to prevent even greater environmental damage if a tanker breaks up because of prolonged stranding.

2. In support of Recommendation 1 and other Regime 1 response approaches, clear lines of authority should be established for the Coast Guard to take more rapid control of the situation and to take the best course of action.

3. Ballasting and other tanker stabilization techniques and equipment systems should be developed for initial responses to tanker casualties in heavy weather. Portable mooring systems (ship or helicopter deployed) should be considered.

4. Improvements should be made in ship and cargo assessment techniques to provide more rapid information flow for decisions on the proper course of action--particularly for ballasting, jettisoning, or similar quick-response operations.

5. Techniques for mooring and controlling receiving or flaring vessels during tanker off-loading operations in heavy weather should be developed to the greatest extent possible.

6. The feasibility of significantly improving the Coast Guard salvage capability, either by building from within or by transferring some of the Navy capabilities, should be studied. Improvements in salvage techniques, such as use of low-response platforms, etc., should be included in the studies. (Cargo off-loading is generally considered part of an overall salvage effort, except where breached tanks must be off-loaded; off-loading is still the most effective method for lowering the ground reaction in a salvage operation, but it is not considered a quick response technique for heavy weather application.)

Regime 2

1. Development of dispersant systems for both vessel and aircraft application should be started. Special emphasis should be given to establishing inventory levels, storage sites, and to solve other logistics problems. Contractor capabilities as well as in-house capabilities should be considered. Streamlining the dispersant use authorization procedure with the EPA to improve responsiveness should also be investigated.

2. Development studies for a dedicated skimmer system should be started. Emphasis should be given to twin-hull vessels (SWATH or catamarans) utilizing a sorbent skimming mechanism, but other concepts could be given further considerations as well. Multi-mission capabilities should be considered to increase system utility. A 6 to 8 year development effort is anticipated.

3. To up-grade heavy weather skimming capabilities until dedicated skimmers are developed, Vessel of Opportunity Skimming Systems (VOSS) should be developed in parallel with dedicated skimmers. VOSS systems could possibly be ready in 2 - 3 years. Rope mop, reusable sorbents, or other concepts should be considered for the skimming mechanism, to be used on vessels with adequate oil storage capacity, such as certain offshore supply boats and small tankers or barges. Coast Guard vessels could be used if a towed oil receiver was utilized. If VOSS skimmers proved more successful than envisioned at this time, procurement of the dedicated skimmers could be delayed or terminated before large sums of money were committed for construction.

4. In support of Recommendation 3, prearrangements with owners of suitable and normally available VOSS vessels and other non-Coast Guard support vessels (receiving barges, tugs, etc.) should be made in order to realize the benefits of quick-response approach to oil spill utilization. This also applies for dispersant systems (vessels and aircraft) and other skimming methods.

5. For use until VOSS or dedicated skimmers are available, the capabilities of the Coast Guard skimming barrier could be upgraded for heavy weather use. This system may give limited utility in Sea State 4, but suitable support equipment must also be available (oil-water separators, receiving vessels, etc.).

General, for both regimes

1. An orderly decision-making procedure for determining the best responses to a given oil spill or tanker casualty should be developed. In the case of spills, a balance of skimming and dispersant approaches should be included.

2. Better techniques for making liquid transfers between low-speed response vessels in heavy weather should be developed. Areas to be addressed should include recovered oil transfers to barges or other receivers, and dispersant resupply to spraying vessels. Floating hose usage should also be considered.

3. High-volume flaring system development should be continued. Systems for flaring both skimmed oil and off-loaded cargo should be considered.

4. Major training exercises for heavy-weather response systems should be conducted. These exercises would provide personnel training and identify problem areas. All logistics functions, as well as major system components, should be involved.

5. In addition to the principal system development recommendations given above, several other sub-systems or components appear to be worthy of further consideration. These are:

a. Vessel-mounted slick tracking aids (radar, etc.) for guidance in following the slick.

b. Floating breakwaters with oil storage capacity.

c. Cargo heating systems for ADAPTS off-loading pumps.

d. Cargo and ship casualty assessment techniques.

e. Portable mooring systems for casualty vessel--ship or helicopter deployed.

f. Mooring systems for barges or other receivers during off-loading operations.

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APPENDIX A

Listing of Significant Variables

The variables (element features) listed in the following table need definition and values associated with them before they can be used for analysis. For this study, many of the values will be specified by the conditions of the scenarios. In reality, however, values may have to be estimated through more or less objective or subjective methods. The features presented herein, therefore, are grouped according to their usual significance and method of determination. The definition of these groups are as follows:

Group 1: Features with values that normally vary from situation to situation and are usually significant in controlling the results of important interface activities, and which usually have quantifiable or objective values or limits associated with them in extreme weather situations.

Group 2: Features with importance and variance similar to the above case, but which usually have less quantifiable or more subjective values or limits associated with them in extreme weather situations.

Group 3: Features with values that do not normally vary from situation to situation, and are usually taken for granted, or that have lesser influence or a low probability of influence on the results of important interface activities, except possibly in special cases, or that influence only normally unimportant, unusual, or improbable activities.

For some features,boundary values can be established. A lower limit is referred to as a minimum constraint value (MCV). This value, where it exists, defines a minimum value of an element feature, above which an extreme weather situation is considered to exist. Only a few element features have such values, such as the wind speed and wave conditions that define a sea state 4. An upper limit can be a natural limiting value of a feature (NLV), or a mission performance requirement (MPR), which can be defined

as a value that establishes the limit of consideration for extreme weather situations or responses. Examples are the wind speed and wave conditions that define a sea state 7, beyond which less than a one percent probability of occurrence exists.

TABLE A1. SIGNIFICANT FEATURES AND VARIABLES

Features	Values of MCV, NLV, MPR
WATER	
Group 1	
1. Temperature	MCV, NLV, MPR = -2° to $+33^{\circ}C$
2. Depth	NLV = 0' or vessel draft if grounded
3. Velocity (current, relative velocity, velocity in conduits, etc.)	NLV = 5.6 knots current
4. Wave height, length, and spectral properties (including tides)	NLV = sea state 7 MCV = sea state 4 MPR = sea state 7
5. Pressure (with depth and in conduits or vessels)	
6. IR, UV, and other properties used to differentiate oil slicks from water in surveillance and detection systems	
Group 2	
1. Type, size, and quantity of debris present	
2. Turbulence properties (rate of generation and intensity)	
3. Dispersed oil component content and stability of mixture	
4. Rate of energy dissipation in surface layers (viscosity effects)	
Group 3	
1. Density	
2. Salinity and other composition (incl dissolved O_2, CO_2, etc.)	
3. Optical properties	
4. Nutrient content and concentration of oil-consuming organisms	
5. Osmotic pressure	
6. Thermal conductivity	
7. Heat capacity	
8. Electrical conductivity	

TABLE A1. SIGNIFICANT FEATURES AND VARIABLES (Cont.)

Features	Values of MCV, NLV, MPR
WATER (cont.)	
Group 3	
9. Viscosity	
10. Biota content	
11. Dissolved oil component content	
12. Air content (air in froth, etc.)	
13. Surface tension	
14. Interfacial tension (with oil)	
15. Oil content (oil-in-water emulsions)	
16. Settling time of o/w emulsions	
17. Tolerance of oil consuming organisms to toxic substances (oil components, dispersants)	
18. Vapor pressure	
19. Evaporation rate	
20. Volume or rate of water under consideration	
OIL	
Group 1	
1. Density	NLV = $\rho_o > \rho_w$ (oil sinks)
2. Composition (oil type)	
3. Temperature	
4. Flash point	
5. Volume and rate of oil under consideration (in specific tank, amount spilled, amount in a slick area, leak rate, pumping rate etc.)	
6. Solids content in oil (sorbents, sand, etc. - modifications to oil properties)	
7. Pour point	
8. Viscosity	
9. Slick area, shape, and location with time	
10. Slick thickness	

TABLE A1. SIGNIFICANT FEATURES AND VARIABLES (Cont.)

Features	Values of MCV, NLV, MPR

OIL (cont.)

Group 1

11. Dispersed droplet sizes and distribution (in water and in air)
12. Surfactant or other additive concentration and type (for dispersion systems)
13. Velocity
14. IR, UV, and other properties used to identify oil slicks in surveillance and detection systems

Group 2

1. Dispersion energy requirements
2. Degree of weathering (measure of present composition and associated chemical and physical properties)

Group 3

1. Surface tension
2. Interfacial tension (with water)
3. Lubricity (slipperiness when spilled on decks, etc.)
4. Vapor pressure
5. Pressure
6. Oil content in mists (from spray)
7. Water content (water-in-oil emulsions)
8. Volatility
9. Electrical conductivity (insulating effects)
10. Penetrating ability (in plastics, elastomers, etc.)
11. Thermal properties (heat capacity, conductivity)

EXPENDABLES

Group 1

1. Physical properties of expendables
2. Chemical properties of expendables

TABLE A1. SIGNIFICANT FEATURES AND VARIABLES (Cont.)

Features	Values of MCV, NLV, MPR
EXPENDABLES (cont.)	
Group 1	
3. Amount and rate under consideration (total requirement and per unit requirement, including losses and wastage; application rate)	
4. Availability and location of source	
5. Oil content and other present-state qualities of sorbents and similar materials	
Group 3	
1. Container size, shape, fittings, etc.	
2. Tolerance to heat and fire (container and expendable)	
3. Tolerance to and degree of atmosphere exposure (precipitation, icing) (container and expendable)	
4. Tolerance to and degree of contamination from other sources (oil, vapors, etc.)	
5. Degree of approach to water saturation and resultant degree of utility	
6. Handling requirements (special equipment, procedures, etc.)	
7. Tolerance to handling methods (processing, reuse, etc. of sorbents,etc.)	
PERSONNEL	
Group 1	
1. Tolerance to, and level of accelerations and other motions (motion sickness)	NLV = 0.1g or less MPR = 0.2g or less
2. Tolerance to heat gain or loss, and level of body temperature (ambient temp., radiation from fires and sunlight, wind chill factors, hypothermia)	
3. Tolerance to, and level of atmospheric pressure - vapors and gases, sunlight, odors, smoke and other exhausts, breathing gas pressure and composition (diving), wind buffeting	

TABLE A1. SIGNIFICANT FEATURES AND VARIABLES (Cont.)

Features	Values of MCV, NLV, MPR
PERSONNEL (cont.)	
Group 1	
4. Tolerance to, and level of liquid exposure (oil components, chemicals, seawater)	
5. Tolerance to, and level of vibrations (types, frequency, amplitude)	MPR = 0.1g at 3Hz to 1g at 60 Hz (or less)
6. Protective clothing and equipment utilized by personnel	
7. Number of personnel under consideration	
Group 2	
1. Stability and coordination (on moving decks, tilted or slippery decks, in wind, or in water)	MPR = 10° roll or less
2. Skill levels (equipment operations, swimming, etc.)	
3. Communication ability (expression, loudness, language, terminology)	
4. Strength capabilities	
5. Visibility in various conditions	NLV = zero visibility
6. Noise tolerance - long and short term	
7. Requirements for food and liquid, sanitary, sleep and rest, medical, social	
8. Hearing ability	MPR = 65db noise interference or less
9. Stamina and endurance (tolerance to fatigue)	
10. Reliability	
Group 3	
1. Reaction and reflex capability	
2. Tolerance to, and level of fear and emotional stress	
3. Tolerance and susceptibility to disease and sickness	
4. Tolerance to, and amount or degree of solid contacts (bumping, slamming, falling)	

TABLE A1. SIGNIFICANT FEATURES AND VARIABLES (Cont.)

Features	Values of MCV, NLV, MPR
PERSONNEL (cont.)	
Group 3	
5. Tolerance to, and level of diving line, or life line, impulse loads	
6. Tolerance to vertigo	
7. Susceptibility to bends and other water-depth problems (divers)	
FIXED OBJECTS AND MACHINERY	
Group 1	
1. System characteristics (function, size, shape, weight, power, capability or requirements, capacities, materials of construction, construction features, etc.)	
2. Deck or aircraft attachment features (tiedowns, etc.)	
3. Inter-connection features (hoses, wires, lines, etc.)	
4. Generation of, or tolerance to, vibrations	
5. Personnel operation and control requirements	
6. Setup requirements (required procedures, operations, space, etc.)	
7. Input and output characteristics (process, fuels, heat, exhaust, etc.)	
8. Rates, capacities, and holdups of inputs and outputs (process, fuels, heat, exhaust, etc.)	
9. Number of units under consideration	
Group 2	
1. Tolerance to, and degree of influence by atmospheric conditions (precipitation, temp., icing, low light levels, high altitude, etc.)	
2. Tolerance to, and degree of influence from contact with seawater or expendables (short-circuiting, corrosion, wave forces, pressure)	
3. Sea bottom characteristics (type of bottom, friction factor with grounded ship, anchor holding force, etc.)	

TABLE A1. SIGNIFICANT FEATURES AND VARIABLES (Cont.)

Features	Values of MCV, NLV, MPR
FIXED OBJECTS AND MACHINERY (cont.)	
Group 2	
4. Required handling procedures and limitation (lift-points, loads, special equipment, etc.)	
5. Noise Output	
6. Mixing characteristics (turbulence generations, agitation, mixing, etc. - for oil and water handling equipment)	
7. Failure modes (functional losses, hazards generated)	
8. Reliability (probability of failure, etc.)	
Group 3	
1. Tolerance to explosive or flammable atmospheres (spark, heat generation)	
2. Maintenance and servicing requirements	
3. Tolerance to, and degree of equipment motions and orientation, with regard to equipment, functioning ("sloshing" in reservoirs, swinging of hooks, etc.)	MPR = up to sea state 7
4. Airdrop or jettisoning capabilities	
5. Aircraft handling provisions	
6. Operating temperatures	
7. Degree of, and tolerance to oil coating or ice coating during operations (slipperiness, swelling of elastomers and plastics, insulating effects)	
8. Shoreline, man-made structures, and other fixed features - characteristics	
9. Design features for underwater or splash-zone operation (hot-taps, pumps, etc.)	
10. Tolerance to debris	
11. Tolerance to impacts (dropping, slamming, etc.)	
FLOATING OBJECTS AND VESSELS (INCLUDING STRICKEN VESSEL)	
Group 1	
1. Vessel dimensions (length, breadth, draft, height, displacement, coefficients of form, etc.)	

TABLE A1. SIGNIFICANT FEATURES AND VARIABLES (Cont.)

Features	Values of MCV, NLV, MPR
FLOATING OBJECTS AND VESSELS (INCLUDING STRICKEN VESSEL) (cont.)	
Group 1	
2. Vessel design characteristics (structural, number and size of tanks, location and type of equipment, deck fittings, handling equipment, etc.)	
3. Damage (location of, size of hole, other structural damage)	
4. Stability criteria (heeling limits, deck cargo and equipment effects, free-surface effects, damaged stability)	MPR = No capsizing in sea state 7 or 21 m/sec wind from worst heading
5. Propulsion characteristics (speed, power, towing capability)	MPR = sea state 7 and 21 m/s wind, 2 kt current, at worst heading direction
6. Steering and control characteristics (prop and rudder immersion, stalling, heading requirements in seas, etc.)	MPR = Ability to maintain any course within 5^{o} in s.s. 7 and 21 m/s wind and to maintain course within ±20', stop in 20 hull lengths and have a tactical dia. of 20 hull lengths or less in s.s. 4 and 10m/s wind and 2 kt. current
7. Navigation capabilities (radar, radio systems, sonar)	
8. Communication capabilities (radio, lights, satellite, etc.)	
9. Emergency features (extra power, pumping systems, fire systems, etc.)	
10. Cargo characteristics (type, amount, location, etc., oil - other)	
11. Anchoring and mooring capabilities (holding power in various bottoms, depths, winch capabilities, fendering capabilities)	

TABLE A1. SIGNIFICANT FEATURES AND VARIABLES (Cont.)

Features	Values of MCV, NLV, MPR
FLOATING OBJECTS AND VESSELS (INCLUDING STRICKEN VESSEL) (cont.)	
Group 1	
12. Operational trim, draft, speed, drag	
13. Duration at sea	
14. Vessel motions in a seaway (including accelerations, deck angles)	
15. Ground reaction magnitude and location (grounded vessel)	
16. Damaged vessel list, trim, and draft	
17. Number of units under consideration and availability (location, etc.)	
18. Availability of on-board support systems for certain response operations	
Group 2	
1. Turbulence-energy input into surface water and oil	
2. Deck "slipperiness" (icing, oil, water)	
3. Reliability	
Group 3	
1. Tolerance to slamming and tendency to slam	MPR - one slam/ minute or less
2. Hotel facilities (personnel provisions - mess, sanitary, sleeping, social, medical)	
3. Characteristics under tow	
4. Maintenance and servicing requirements	
5. Probability and degree of decks awash	
6. Drift (location, course; under load, in seaway)	
7. Vibration (amplitudes, frequencies)	
8. Crew size	

(See also Casualty Parameters)

TABLE A1. SIGNIFICANT FEATURES AND VARIABLES (Cont.)

Features	Values of MCV, NLV, MPR
AIRCRAFT	
Group 1	
1. Payload - within body and as slung cargo (weight and volume)	
2. Hoist capacity	
3. Fuel capacity	
4. Speed	
5. Navigational capability	
6. Capabilities for slick detection and tracking	
7. Range (related to fuel, payload, and personnel loads, and also to time-on-station)	
8. Passenger capacity	
9. Altitude restriction in weather (minimum and maximum)	
10. Wind limits (for operations and landing)	
11. Landing platform motion limits (vessel, structure, water)	
12. Runway requirements	
13. Communications capability	
14. Field maintenance and support requirements	
15. Number of aircraft of a given type under consideration and availability (location, etc.)	
16. Aircraft type, size, performance and control characteristics (including clearance requirements, hovering limits, etc.)	
Group 2	
1. Visibility requirements	
2. Tolerance to impacts (weight and CG changes) on aircraft or suspended cargo (loading onto decks or water)	
3. Reliability	
4. Maneuverability and stability under load (helicopters - slung or towed loads in forward flight)	
5. Time on station	

TABLE A1. SIGNIFICANT FEATURES AND VARIABLES (Cont.)

Features	Values of MCV, NLV, MPR
AIRCRAFT (cont.)	
Group 3	
1. Fuel type and consumption rate	
2. Airdrop capabilities	
3. Crew size	
4. Tiedown requirements	
5. Vessel towing capabilities	
6. De-icing capability and level of icing (light, medium, heavy)	
7. Static charges on aircraft (helicopters)	
8. Cargo jettisoning and releasing provisions	
9. Size, weight, stability and other characteristics that determine motions while landed on the water surface (helicopters)	
ATMOSPHERE	
Group 1	
1. Wind energy (transfer to water to make waves and turbulence, current, spray, dispersion, etc.; also transfer to vessels and aircraft to cause drifting)	MCV = 17 knots
2. Cloud cover (altitude, type, density)	
3. Speed and direction (including wind, air currents from blowers, relative wind from moving vessels, etc.)	
4. Temperature (ambient, flames, within closed spaces, etc.)	
5. Precipitation type, rate and energy content (rain, snow, sleet, hail)	
6. Fog	
7. Wind fetch and duration	
Group 2	
1. Noise (frequency, intensity - from all sources, including wind, water, thunder, etc.)	

TABLE A1. SIGNIFICANT FEATURES AND VARIABLES (Cont.)

Features	Values of MCV, NLV, MPR
ATMOSPHERE (cont.)	
Group 2	
2. Turbulence characteristics	
Group 3	
1. Density	
2. Pressure (diving gases, high altitudes, or from blowers, etc.)	
3. Composition of breathing gas (diving gases)	
4. Heat capacity	
5. Thermal conductivity	
6. Viscosity	
7. Sunlight radiation (equipment heating, sunburn problems)	
8. Ignition temperatures (given vapor concentration)	
9. Radio-inhibiting atmospheric disturbances	
10. Odors	
11. Spray content (sea water)	
12. Humidity	
13. Daylight cycle	
14. Lightning, arcs, sparks, flames, and other intense heat sources in the atmosphere)	
15. Gas and vapor concentrations (exhausts, petroleum and chemical vapors)	
16. Solids concentrations (smoke)	
17. Other liquid concentrations (chemical sprays, oil sprays)	
18. Wind fetch and duration	
19. Volume and rate of atmosphere element under consideration	
CASUALTY PARAMETERS (SEE FLOATING OBJECTS AND VESSELS ALSO)	
Group 1	
1. Location of casualty	

TABLE A1. SIGNIFICANT FEATURES AND VARIABLES (Cont.)

Features	Values of MCV, NLV, MPR
CASUALTY PARAMETERS (SEE FLOATING OBJECTS AND VESSELS ALSO) (cont.)	
Group 1	
2. Type of casualty	
3. Proximity to endangered resources and human use areas	
4. Distance from closest mobilization point(s)	
5. Amount of oil to be lightered or transferred	
6. Pull required to free grounded tanker, as function of cargo transfer	
7. Condition of ship's power plant, communications facilities, etc.	
8. Change in draft upon grounding	
9. Extent of damage (severity and location)	
10. Spilling occurrence, if any	
11. Degree of hogging or sagging	
12. Ground reaction and location (grounded vessels)	
Group 2	
1. Grounded vessel "liveliness"	
Group 3	
1. Speed of vessel before grounding	
2. Time of casualty	
3. Amount of ballast required for ballasting	

APPENDIX B

Response System Evaluation Summaries

Response System Evaluation Summary

System: Cargo jettisoning using ship's pumps (Regime 1)

Important Development Needs:	Estimated Development Time	Estimated Development Expenditures
Development of acceptable political climate	2 - 8 yrs	unknown
Effective spill response systems to mitigate the effects of the jettisoned oil	2 - 8 yrs*	$1M - $15M
Rapid ship and cargo assessment techniques	1 - 3 yrs	$50K - $500K

Potential for Success:

Sea State 4: Good

Sea State 5: Good

Sea State 6: Fair to good

Response Speed: Fast - standby tug availability may control

Impacts on Coast Guard: Impacts do not include new spill response system impacts.

Vessels: Low - standby tug assistance needed

Aircraft: Low

Siting: Low

Manning: Low

Procurement Costs: Low

Operating Costs, Per Unit of Oil: Considering the entire cargo, costs are low.

Other Comments: Education of the public and the assurance that the resulting spill can be cleaned up or mitigated are the keys to successful implementation.

Recommendations: Pursue this approach.

* Key or critical path-type project

Response System Evaluation Summary

System: Ship ballasting and stabilizing using portable water pumping system (Regime 1)

Important Development Needs:	Estimated Development Time	Estimated Development Expenditures
High-capacity pumping systems	< 2 yrs	$20K - $200K
Tanker mooring systems (for additional stabilization)	< 2 yrs	$20K - $200K
Rapid ship and cargo assessment techniques	1 - 3 yrs*	$50K - $500K
		$90K - $900K

Potential for Success:

Sea State 4: Fair to good

Sea State 5: Fair

Sea State 6: Poor to fair

Response Speed: Rapid

Impacts on Coast Guard:

Vessels: Low

Aircraft: Low

Siting: Low - ADAPTS sites should be adequate.

Manning: Low - special training for Strike Teams and assessment system personnel.

Procurement Costs: Low to moderate - $30K - $50K per pumping system.

Operating Costs, Per Unit of Oil: Very low

Other Comments: Not a cure-all - requires off-loading later on. Essentially buys time until weather subsides and/or off-loading equipment is mobilized. Water ballasting required anyway during off-loading.

Recommendations: Proceed with development studies.

* Key or critical path-type project

Response System Evaluation Summary

System: Cargo off-loading into barges using portable pumps (Regime 1)

Important Development Needs:	Estimated Development Time	Estimated Development Expenditures
Barge or receiver mooring systems	<2 yrs	$20K - $200K
Floating hose systems	<2 yrs	$20K - $200K
		$40K - $400K

Potential for Success:

Sea State 4: Good

Sea State 5: Fair to good

Sea State 6: Poor to fair

Response Speed: Relatively slow--best for controlled salvage efforts.

Impacts on Coast Guard:

Vessels: Low -- charter vessels probably required

Aircraft: Low -- existing helicopters adequate for transfers.

Siting: Low -- TSC recommendations will probably be adequate.

Manning: Low -- Strike Team adequate.

Procurement Costs: Relatively low additional expense required.

Operating Costs, Per Unit of Oil: Low, depending on barge/tug charter costs.

Other Comments: Practice needed to develop barge mooring and transfer procedures.

Recommendations: Develop both areas shown above; other systems may have applications for this technology, also.

Response System Evaluation Summary

System: Cargo off-loading to burners, using portable pumps (Regime 1)

Important Development Needs:	Estimated Development Time	Estimated Development Expenditures
High capacity portable flaring systems) Support platforms for flame systems (barges, etc.))	3 - 6 yrs*	$1M - $5M
Mooring and hose systems for platforms	<2 yrs	$40K - $400K

Potential for Success:

Sea State 4: Good - fewer logistics problems than with recovery.

Sea State 5: Fair to good - (same comment)

Sea State 6: Poor to fair - probably better than receiver systems.

Response Speed: Relatively slow -- best for controlled salvage efforts.

Impacts on Coast Guard:

Vessels: Moderate -- new type vessels or structures required.

Aircraft: Low -- existing helicopters adequate for transfers.

Siting: Moderate -- sites for system stationing required.

Manning: Moderate -- special personnel and training needed.

Procurement Costs: Relatively high -- $200K - $500K for only 1 or 2 ADAPTS pumps.

Operating Costs, Per Unit of Oil: Low -- minimum logistics costs.

Other Comments: Capabilities may be limited by safety considerations. Development efforts could vary considerably depending on the system chosen.

Recommendations: Expand flaring system investigation program to explore newer concepts. Flaring is a key to reducing logistics problems in heavy weather.

* Key or critical path-type project

Response System Evaluation Summary

System: Low-response platform for cargo off-loading support, including high-volume oil burning system

Important Development Needs:	Estimated Development Time	Estimated Development Expenditures
Low response platform suitable for working around stranded tankers	>6 yrs	> $5M
Ducted vertical burner system with power generation capability	>6 yrs	$0.2M - $5M

Potential for Success:

Sea State 4: Good

Sea State 5: Good

Sea State 6: Fair to good

Response Speed: Slow - best for controlled salvage effort where long mobilization time could be tolerated.

Impacts on Coast Guard:

Vessels: Moderate - towing provisions may be required.

Aircraft: Low

Siting: High - special sites needed for berthing.

Manning: High - special manning requirements (permanent crew).

Procurement Costs: High - on order of $15M - $25M.

Operating Costs, Per Unit of Oil: Moderate to high - considering standby costs.

Other Comments: Multi-use capability may help defray expenses. System is only conceptual at this time - many subsystems required.

Recommendations: Appears to be worthy of further study.

Response System Evaluation Summary

System: In-situ cargo burning through bombing and shelling (Regime 1)

Important Development Needs:	Estimated Development Time	Estimated Development Expenditures
Special ordnance and delivery systems	4 - 6 yrs*	$1M to $5M

Potential for Success:

Sea State 4: Poor

Sea State 5: Poor

Sea State 6: Poor

Response Speed: Fairly rapid, but limited by military aircraft availability.

Impacts on Coast Guard:

Vessels: Low - Moderate -- WHEC required for shelling.

Aircraft: Low -- Navy or Air Force aircraft strongly impacted.

Siting: Low -- Other air bases affected, but not strongly.

Manning: Low -- training of other service personnel needed.

Procurement Costs: Moderate -- inventory of special bombs or missiles can be expensive.

Operating Costs, Per Unit of Oil: Low to moderate

Other Comments: Involves considerable environmental risk. Most attractive as a last-resort method.

Recommendations: Do not proceed with development work, but be alert to new developments that might enhance performance.

* Key or critical path-type project

Response System Evaluation Summary

System: In-situ cargo burning using planted explosives (Regime 1)

Important Development Needs:	Estimated Development Time	Estimated Development Expenditures
Optional configurations and procedures for explosive arrays	2 - 4 yrs*	$0.2M - $1.0M

Potential for Success:

Sea State 4: Poor

Sea State 5: Poor

Sea State 6: Poor

Response Speed: Slow -- elaborate setup required.

Impacts on Coast Guard:

Vessels: Low

Aircraft: Low -- existing helicopters can handle transfers.

Siting: Moderate -- special storage facilities required.

Manning: Moderate -- specialized personnel required.

Procurement Costs: Low -- explosives for a 100,000 dwt tanker approximately $50K-$100K.

Operating Costs, Per Unit of Oil: Low

Other Comments: Whole tanker cannot be opened adequately. Difficult setup.

Recommendations: Do not develop this concept.

* Key or critical path-type project

Response System Evaluation Summary

System: Dispersant system - vessel application methods (spray booms)

Important Development Needs:	Estimated Development Time	Estimated Development Expenditures
Improved liquid carrying and/or transfer techniques for on-site resupply to spraying vessels, and a good logistics system	2 - 4 yrs	$100K - $1M
Reliable sources of spraying vessels	1 - 2 yrs	unknown
Cheaper but still highly effective dispersants with low toxicity	on-going	unknown
Identify areas where dispersants can be used	1 - 2 yrs	$20K - $200K

Potential for Success:

Sea State 4: Good

Sea State 5: Fair to good

Sea State 6: Fair

Response Speed: Moderate to slow - mobilization of supplies (dispersants) can be a problem.

Impacts on Coast Guard:

Vessels: Low to moderate - Coast Guard vessels have inadequate storage potential, but other vessels can be used.

Aircraft: Low

Siting: High - storage of bulk dispersants and logistics considerations.

Manning: Low to moderate

Procurement Costs: High - inventory supply and facilities may run $20M - $25M. Spray systems inexpensive, however.

Operating Costs, Per Unit of Oil: High

Other Comments: More cost effective on thin slicks where other methods (skimming) are inefficient. May not be suitable for environmentally-sensitive areas.

Recommendations: Pursue development studies concurrently with aircraft application methods.

Response System Evaluation Summary

System: Dispersant system - aircraft application methods

Important Development Needs:	Estimated Development Time	Estimated Development Expenditures
Development of forest-fire fighting equipment (MAFFS)	1 - 2 yrs	$50K - $500K
Reliable commercial aircraft sources	<1 yr	unknown
Logistics system	2 - 4 yrs	$100K - $1M
Identify areas where dispersants can be used	1 - 2 yrs	$20K - $200K
		$170K -$1.7M

Potential for Success:

Sea State 4: Good

Sea State 5: Good

Sea State 6: Good

Response Speed: Fast to moderate - mobilizing bulk dispersant supplies could present problems.

Impacts on Coast Guard:

Vessels: Low

Aircraft: Moderate (MAFFS-type system) to high (spray booms) for C-130 aircraft

Siting: High - storage of bulk dispersant,and logistics considerations.

Manning: Low to moderate

Procurement Costs: High - inventory supply and facilities may run $20M - $25M, MAFFS $575K unmodified.

Operating Costs, Per Unit of Oil: High

Other Comments: Highest cost, but best sea state capability of any slick response method. May not be suitable for environmentally-sensitive areas.

Recommendations: Pursue development studies concurrently with vessel-application methods.

Response System Evaluation Summary

System: Dedicated skimmer - multi-use twin-hull ship

Important Development Needs	Estimated Development Time	Estimated Development Expenditures
Skimmer vessel (not incl. cost of first ship)	6 - 8 yrs*	$5M - $10M
Methods for transferring skimmer cargo to receivers (barges)	1 - 2 yrs	$20K - $200K
Floating hoses for cargo transfers	1 - 2 yrs	$20K - $100K
Reliable sources of barges and tugs	1 - 2 yrs	unknown

Potential for Success:

Sea State 4: Good

Sea State 5: Fair

Sea State 6: Poor

Response Speed: Moderate - receiving barge/tug availability a key.

Impacts on Coast Guard:

Vessels: High - can supplant existing vessel functions.

Aircraft: Low

Siting: Moderate - special port facilities may be needed, and range should be limited.

Manning: Moderate - training needed but overall manning level could stay relatively constant.

Procurement Costs: High - $12M - $15M per vessel, but only around $3M if 80% of vessel time used for other purposes.

Operating Costs, Per Unit of Oil: Low, at moderate efficiencies (high at very low efficiency).

Other Comments: Appears to be technically the best approach to heavy weather skimming. Not efficient in extremely thin slicks; supplementing skimming with dispersants may be desirable.

Recommendations: Initiate development studies, concentrating on SWATH ships or catamarans, with sorbent skimming mechanisms.

*Key or critical path-type project

Response System Evaluation Summary

System: Vessel of Opportunity Skimming System (VOSS)

Important Development Needs:	Estimated Development Time	Estimated Development Expenditures
Effective skimmer modules and vessel attachment gear	2 - 3 yrs*	$100K - $500K
Reliable sources of support vessels and receivers (barges, tugs)	1 - 2 yrs	unknown
Floating hoses for cargo transfer	1 - 2 yrs	$20K - $100K
Methods for transferring skimmer cargo to receivers	1 - 2 yrs	$20K - $200K
		$140K - $800K

Potential for Success:

Sea State 4: Fair to good

Sea State 5: Poor to fair

Sea State 6: Poor

Response Speed: Moderate - vessels, barge, and tug acquisition together could pose problems. Pre-adapted vessels could shorten time requirements considerably.

Impacts on Coast Guard:

Vessels: Moderate - WLB's could be support vessels if towed oil receivers were utilized. Other vessels would be better.

Aircraft: Low

Siting: Low - ADAPTS sites would be suitable for skimming modules.

Manning: Low - cross-training needed but existing personnel may be adequate.

Procurement Costs: Moderate - on order of $100K-$200K per vessel system.

Operating Costs, Per Unit of Oil: Low, at moderate efficiencies

Other Comments: Individual system capacities may be small. Skimmer design (unknown at present) critical. Probably not as sound an approach as dedicated skimmer technically, but better than other heavy weather skimming systems.

Recommendations: Develop systems. Could provide better protection than existing boom/skimmer systems, at least up to the time when dedicated skimmers are available. If VOSS systems are good, procurement of dedicated skimmers could be delayed or development terminated.

*Key or critical path-type project

Response System Evaluation Summary

System: Skimming barrier

Important Development Needs:	Estimated Development Time	Estimated Development Expenditures
Improvements in existing Coast Guard system (longer hoses, etc.)	1 - 2 yrs	\$20K - \$100K
Reliable sources of receiving vessels (barges and tugs)	1 - 2 yrs	unknown
Floating hoses for cargo transfer	1 - 2 yrs	\$20K - \$100K
Methods for handling receiving barges or receivers in heavy weather	1 - 2 yrs	\$20K - \$100K
		\$60K - \$300K

Potential for Success:

Sea State 4: Fair

Sea State 5: Poor

Sea State 6: Poor

Response Speed: Moderate - acquisition of all of the vessels involved could pose problems.

Impacts on Coast Guard:

Vessels: Low to moderate - more bow thruster-WLB's may be needed.

Aircraft: Low

Siting: Low - fits in with existing plans. O/W separators should be included.

Manning: Low - existing manpower adequate.

Procurement Costs: \$50K for a separator, plus skimmer sections and pumping modules.

Operating Costs, Per Unit of Oil: Low to moderate - depending on efficiency, which could be relatively low.

Other Comments: Probably the best of the barrier-type skimming concepts, but needs more testing.

Recommendations: Continue work on this system. It is probably the best approach for attaining any heavy weather skimming capability, limited as it may be, within the next few years.

Response System Evaluation Summary

System: Barrier system with skimmer independent of the barrier, and umbilical supported from a distant support ship (OWOCS/OWORS)

Important Development Needs:	Estimated Development Time	Estimated Development Expenditures
Launch and set-up methods	1 - 2 yrs	$20K - $100K
Reliable sources of support vessels and receivers (barges, tugs)	1 - 2 yrs	unknown
Floating hoses for cargo transfer	1 - 2 yrs	$20K - $100K
Methods for handling receiving barges or receivers in heavy weather	1 - 2 years	$20K - $100K
		$60K - $300K

Potential for Success:

Sea State 4: Poor to fair

Sea State 5: Poor

Sea State 6: Poor

Response Speed: Moderate to slow - acquisition of launch/support vessel, towing vessels, and receivers together could pose problems.

Impacts on Coast Guard:

Vessels: Moderate - Coast Guard vessels not suitable for launching, but acquisition of a suitable vessel can be a problem.

Aircraft: Low - systems exist already

Siting: Low - systems exist already

Manning: Low - systems exist already

Procurement Costs: Low - major components in inventory already (except more OWORS would be needed).

Operating Costs, Per Unit of Oil: Low, at moderate efficiencies.

Other Comments: Operational control and setup problems severe in heavy weather.

Recommendations: Do not pursue development - utilize existing components for relatively calm sea situation.

Response System Evaluation Summary

System: Barrier system with skimmer independent of the barrier, with skimmer supported by a boom from a nearby ship

Important Development Needs:	Estimated Development Time	Estimated Development Expenditures
Reliable sources of support vessels and receivers (barges, tugs)	1 - 2 yrs	unknown
Floating hoses for cargo transfer	1 - 2 yrs	\$20K - \$100K
Methods for transferring skimmer cargo to receivers	1 - 2 yrs	\$20K - \$200K
		\$40K - \$300K

Potential for Success:

Sea State 4: Poor to fair

Sea State 5: Poor

Sea State 6: Poor

Response Speed: Moderate - depends on acquisition of adequate vessels

Impacts on Coast Guard:

Vessels: Moderate - Coast Guard vessels unsuitable for launching, but acquisition of vessels can be a problem.

Aircraft: Low

Siting: Moderate - large components involved, but barrier facilities should be sufficient.

Manning: Low - trained personnel needed but cross-training may be sufficient.

Procurement Costs: Barrier existing, skimmers \$180K each

Operating Costs, Per Unit of Oil: Low, at moderate efficiencies

Other Comments: Control problems in heavy seas can be severe - problem is mainly the close proximity of ship to barrier, and ship motions.

Recommendations: Do not pursue for heavy weather use.

Response System Evaluation Summary

System: Skimmer with herding barrier attached.

Important Development Needs:	Estimated Development Time	Estimated Development Expenditures
Reliable sources of receiving vessels (barges and tug)	1 - 2 yrs	unknown
Hoses for cargo transfer	1 - 2 yrs	\$20K - \$100K
Methods for handling receiving hoses or receivers in heavy weather	1 - 2 yrs	\$20K - \$100K
Improved barrier to skimmer transitions	1 - 2 yrs	\$20K - \$100K
		\$60K - \$300K

Potential for Success:

Sea State 4: Poor

Sea State 5: Poor

Sea State 6: Poor

Response Speed: Moderate to slow - barges and towing vessels are problems. Skimmer and barrier may need tow to site at slow speed.

Impacts on Coast Guard:

Vessels: Low to moderate - more bow thruster-WLB's may be needed.

Aircraft: Low

Siting: Moderate to high - skimmers may need permanent port facilities.

Manning: Low to moderate - depends on skimmer design

Procurement Costs: Moderate to high-- \$100K - \$500K for skimmer

Operating Costs, Per Unit of Oil: Moderate to high - because of low anticipated efficiency.

Other Comments: Barrier-skimmer motion mismatch a problem.

Recommendations: Do not pursue this approach for heavy weather.

Response System Evaluation Summary

System: Enhanced biodegradation of oil slicks

Important Development Needs:	Estimated Development Time	Estimated Development Expenditures
Complete system development, directed towards vessel and air application methods	unknown	unknown-too early to be definitive

Potential for Success:

Sea State 4: Poor to fair - depends on oil quantity

Sea State 5: Poor to fair

Sea State 6: Fair

Response Speed: Fairly slow initial response capability, and slow assimilation process.

Impacts on Coast Guard:

Vessels: Low to moderate - could be vessel applied.

Aircraft: Low to moderate - could be aircraft applied.

Siting: High - logistics a problem, and special facilities may be required.

Manning: Low to moderate

Procurement Costs: High - inventory for 100,000-ton spill approximate $25M.

Operating Costs, Per Unit of Oil: High - probably highest of any method.

Other Comments: Integration with dispersant techniques may improve success potential.

Recommendations: Do not actively pursue, but possibly fund some exploratory studies. Too early to make a good assessment of potential.

Response System Evaluation Summary

System: Slick sinking using dredged sand (treated)

Important Development Needs:	Estimated Development Time	Estimated Development Expenditures
Adaptation of technology to U. S. vessels (suction dredges)	2 - 4 yrs	$100K - $500K

Potential for Success:

Sea State 4: Fair to good

Sea State 5: Poor to fair

Sea State 6: Poor

Response Speed: Moderate to slow - depends on degree of pre-outfitting of vessel.

Impacts on Coast Guard:

Vessels: Low

Aircraft: Low

Siting: Low - Corps of Engineers' vessels involved.

Manning: Low - Corps of Engineers' vessels involved

Procurement Costs: Moderate - adaptation probably $300K per vessel

Operating Costs, Per Unit of Oil: Low

Other Comments: Long term effects on bottom life are the biggest drawback.

Recommendations: Do not pursue.

Response System Evaluation Summary

System: Slick burning using confining booms

Important Development Needs:	Estimated Development Time	Estimated Development Expenditures
Effective fire-proof barriers and deployment procedures	4 - 6 yrs	\$1M - \$5M

Potential for Success: (If fire-proof barrier can be developed)

Sea State 4: Poor to fair

Sea State 5: Poor

Sea State 6: Poor

Response Speed: Fast to moderate - no receiving barges to be concerned with.

Impacts on Coast Guard:

Vessels: Low

Aircraft: Low

Siting: Low to moderate

Manning: Low

Procurement Costs: Unknown, but could be on the order of \$100K - \$200K per system.

Operating Costs, Per Unit of Oil: Low

Other Comments: Feasibility not demonstrated yet for heavy weather, but outlook is not good.

Recommendations: Do not actively pursue.

Response System Evaluation Summary

System: Non-reusable sorbent application for slicks

Important Development Needs:	Estimated Development Time	Estimated Development Expenditures
Distribution (spreading), recovery, and handling technology for rapid utilization. Logistics considerations	4 - 6 yrs	$1M - $5M

Potential for Success:

Sea State 4: Poor to fair - logistics and recovery controlling

Sea State 5: Poor

Sea State 6: Poor

Response Speed: Fast to moderate - by aircraft.

Impacts on Coast Guard:

Vessels: Moderate - for collecting and treating sorbents (VOSS).

Aircraft: Moderate to high.

Siting: Moderate - Large stocks required.

Manning: Low to moderate.

Procurement Costs: Moderate (cotton-wasties) to high (polyurethane foam).

Operating Costs, Per Unit of Oil: Low (cotton-wasties) to high (polyurethane foam).

Other Comments: Most useful for initial spill response to avoid excessive thinning before other response systems arrive.

Recommendations: Do not pursue.

APPENDIX C

Seakeeping Analyses

1. Computation of Seakeeping Motions for Monohulls

Table C1 gives the particulars of ships that are representative of those which may be involved in oil recovery operations. Individual ships have been selected from this list to represent the more common ships. The selection of these ships depended on the general hull shape, length and availability of good data.

The motions that influence crew performance and interfere with operations between ships are, vertical accelerations, vertical displacement and roll. Vertical motions affect the ability to perform tasks in three ways: the motions cause motion sickness, water on the deck is a safety hazard, and the motions directly interfere with the movement of objects on deck or over the side. With these problems in mind, the following values were estimated: the vertical acceleration at stations zero (bow) and ten (amidships), the vertical relative motion at station one, and the probability of a relative motion that immerses the deck at station one to a value one foot below the local water height.

The various quantities describing ship motion were estimated using a systematic computer study of seakeeping motions presented by Loukakis and Chryssostomidis[C1]. The authors computed the seakeeping properties of a parametric family of hulls based on the Series 60 hulls. Given the C_B, L/B, B/T, Fn and $H_{1/3}$, a quick and accurate evaluation of ship motions in head seas can be made. Several of the ships fall outside the range of the tables. These vessels were evaluated using a three point extrapolation. The dependence of ship motions on the characteristic hull parameters is smooth and permits such extrapolation. To check the general

TABLE C1. LIST OF SHIPS USED IN COAST GUARD SEAKEEPING STUDY

(Ships are entered in order of increasing LWL. Estimates of vertical motions, accelerations and roll amplitudes were made for those ships underlined.)

Vessel	LWL, ft	B, ft	T, ft	Displ. Long Ton	CB
WPB Patrol Boat	78	18	6	66	.27
YTB Large Harbor Tug	89	25	9.9	-	-
WPB Patrol Boat	90	20	6	105	.34
<u>T-06 Ocean Tug</u>	90.5	26.1	12.7	382.3	.44
F-18 Atlantic Coast Dragger	93.8	23.6	11.3	356.2	.50
YTM Medium Harbor Tug	105	27	11.6	384	.41
WYTM Medium Harbor Tug	110	27	11	370	-
<u>T-10 Ocean Tug</u>	146	32.8	14.5	1093.3	.55
F-19 Fishing Boat	148.3	30.4	14.5	1098.5	.59
WLM Buoy Tender	150	31.5	6.5	522	.59
WLM Buoy Tender C-Class	157(OA)	33	6	512	≈.58
WLB Buoy Tender	170	37	12	1087	.50
<u>S-04 Supply Boat</u>	170.95	37.53	12.61	1507.75	.65
Side Trawler	180	32	15	1400	.57
ATF Navy Ocean Tug 67-162	195	39	15.5	1675	.50
ARS Navy Salvage	207	39	13.0	1900	.63
<u>ASR 7-16 Sub Rescue Ship</u>	240	42	14.4	2290	.55
<u>AO Navy Oiler</u>	640	86	35.1	38,000	.64
<u>T6-S-93a Tanker</u>	660	90	35	47,300	.79
Arco Anchorage (Tanker)	850	138	51.75	144,700	.82
<u>T8-S-100b (Tanker)</u>	859	105.8	49.0	106,700	.84
Standard River Barge	191.6	35	10.4-6.3	1705-939	-
<u>Dravo Barge</u>	195.0	35	12.5-2.6	2321-278	.95
Crowley Work Platform	200	54	10.4-2.0	-	-
Berkeley Barge	360	80	27	-	-
Crowley Barge	430	80	21.5-4	16,674	.79
Humble Barge	540	90	30	35,580	.85

TABLE C1. (Continued)

Specialized Vessels for Oil Recovery

Vessel	LOA, ft	Beam, B (One Hull) ft	T, feet	Configuration
Bennett Mark 4	40	12 (-)	7	Catamaran
Bennett Mark 9A	53	21 (-)	-	Catamaran
JBF-DIP-5001	68	17	6	Monohull
MIPOS 25	82	29 (-)	7	Catamaran
API	90	-	-	Catamaran
Bridgestone L-Type	91	41 (14)	8.4	Catamaran
Oil Mop 100	100	43 (12)	9.4	Catamaran
Trygve Thune A/S Oil Scooper	102	33	13	Barge
Oil Mop 140	140	50 (17)	10	Catamaran
JBF-DIP-7001	160	36	11.5	Monohull

application of the parametric study to work boats and tugs, comparisons were made between the results of a detailed computer study[C2] and estimates from the seakeeping series. The seakeeping series gives results which are within 10 percent of the detailed computations.

The estimates for the accelerations, relative motions, slamming, and deck wetness are presented in Table C2, for significant wave heights of 7, 10, and 16 feet, corresponding to the medium $H_{1/3}$ values for sea states 4, 5, and 6, respectively. All values are RMS amplitudes. Only two low Froude numbers were evaluated because they cover the probable working speeds of tow boats and barges; they give an indication of the zero speed motions, and higher speeds generally produce unacceptable motions. Accelerations and velocities for other $H_{1/3}$/LBP values may be obtained by linear interpolation.

The frequency of deck wetness is a function of local freeboard, the relative motion and relative velocity. The number of events per hour is given by (from reference C1):

$$NE = \frac{3600}{2\pi} \exp\left(-f^2/2M^2\right) \frac{V}{M}$$

where,

NE = events per hour

f = local freeboard near the bow, feet.

M = relative bow motion, RMS amplitude, ft

V = relative bow velocity, RMS amplitude, ft/sec

Data on local freeboard is difficult to obtain, so the occurrence of deck wetness is based on freeboard values estimated from photographs or other data, plus one foot to simulate green water. The above equation was also used to estimate slamming, with draft substituted for local freeboard.

TABLE C2. ACCELERATION, MOTIONS, DECK WASH, AND SLAMMING

Fr = 0.1

Vessel	C_B	LWL, ft	T, ft	Fbd+1, ft	$\frac{H_{1/3}}{LWL}$	$H_{1/3}$, ft	Speed, kts	Acceleration, G Sta 0	Acceleration, G Sta 10	Station 1 Relative Motion, ft	Station 1 Relative Vel., ft/sec	Deck Wash/hr	Slams/hr	Comments
T-06 Tug	.44	90.5	12.7	12.4	.08	7	3.2	.23	.11	4.6	5.8	19	16	not good (bad roll also)
					.11	10	3.2	.30	.11	5.6	6.8	60	53	
					.18	16	3.2	-	-	-	-	-		
T-10 Tug	.55	146	14.5	14.0	.05	7	4.1	.22	.09	4.7	5.8	8	6	not desirable (bad roll in all ss)
					.07	10	4.1	.24	.10	5.4	6.4	24	18	
					.11	16	4.1	.29	.13	6.6	7.6	70	59	
WLM (157')	.58	157	6.0	14.3	.04	7	4.2	.17	.04	2.9	4.4	0	102	slamming bad vessel unacceptable
					.06	10	4.2	.18	.05	3.2	4.5	0	139	
					.10	16	4.2	.21	.06	3.7	4.8	0	200	
WLB (180')	.50	170	12.0	14.8	.04	7	4.4	.23	.07	4.7	6.3	5	30	not the best type of vessel (roll bad in most cases, except possibly 7' seas)
					.06	10	4.4	.25	.09	5.3	6.7	15	36	
					.09	16	4.4	.29	.11	6.4	7.6	47	117	
S-04 Supply Boat	.65	171	12.6	16.0	.04	7	4.4	.16	.05	2.6	5.0	0	0*	good (roll possibly bad above 7' seas)
					.06	10	4.4	.18	.06	3.4	5.3	0	1	
					.09	16	4.4	.22	.09	5.0	6.0	4	29	
ARS 6-43	.63	207	13.0	17.0	.03	7	4.8	.19	.04	5.2	5.9	3	29	not bad, better than a WLB (roll bad in 10' & 16' seas)
					.05	10	4.8	.20	.05	5.5	6.1	5	39	
					.08	16	4.8	.22	.07	5.9	6.4	10	55	
ASR 7-16	.55	240	14.4	21.5	.03	7	5.2	.20	.05	5.7	6.4	1	26	about like the ARS, better in deck wash (roll bad in 16' seas and maybe in 10' seas)
					.04	10	5.2	.21	.06	6.1	6.7	1	39	
					.07	16	5.2	.24	.07	6.9	7.3	5	69	

*F-19 fishing boat, side trawler probably acceptable, also.

TABLE C2. ACCELERATION, MOTIONS, DECK WASH, AND SLAMMING (Continued)

Fr = 0.2

Vessel	C_B	LWL, ft	T, ft	Fdbd+1, ft	$H_{1/3}$, ft	Speed, kts	Acceleration, G		Station 1		Deck Wash hr	Slams hr	Comments
							Sta 0	Sta 10	Relative Motion, ft	Relative Vel., ft/sec			
T-06					7	6.4	.25	.18	4.4	6.2	15	13	
					10	6.4	.36	.22	6.0	8.3	94	84	
					16	6.4	-	-	-	-	-	-	
T-10 Tug					7	8.1	.24	.13	4.9	6.4	13	9	
					10	8.1	.28	.15	5.8	7.3	39	32	
					16	8.1	.37	.20	7.6	9.1	126	111	
WLM (157')					7	8.4	.26	.08	3.7	6.0	1	249	
					10	8.4	.29	.09	3.8	6.3	1	273	
					16	8.4	.33	.11	4.0	6.8	2	316	
WLB (180')					7	8.8	.27	.11	5.4	7.2	18	65	
					10	8.8	.31	.13	6.2	8.0	43	114	
					16	8.8	.38	.16	7.7	9.4	110	208	
S-04 Supply Boat					7	8.8	.20	.09	2.6	5.8	0	0	
					10	8.8	.23	.11	3.7	6.3	0	3	
					16	8.8	.29	.13	5.9	7.4	18	73	
ARS 6-43					7	9.7	.28	.11	6.0	7.4	13	68	
					10	9.7	.29	.12	6.4	7.7	20	88	
					16	9.7	.31	.13	7.1	8.2	38	124	
ASR 7-16					7	10.4	.26	.10	6.5	8.0	3	61	
					10	10.4	.29	.11	7.1	8.5	7	88	
					16	10.4	.33	.13	8.3	9.4	23	144	

The magnitude of roll in a given seaway is very sensitive to the details of hull shape and GM, the metacentric height. Both of these quantities may be different for ships of a given class and for different loading conditions. As a result, it is difficult to characterize the rolling behavior of groups of ships, especially when only using the general hull parameters of length, beam, draft, displacement and GM. Typical GM values could be obtained for some of the vessels and are listed in Table C3 along with estimates of the range of natural roll period.

The characteristic period, T_w , of the Pierson-Moskowitz Spectra for the given wave heights falls in the same range as the natural roll periods, as shown below.

$H_{1/3}$, Ft.	T_w, Sec.
6.89	5.6
9.84	6.7
15.75	8.4
19.69	9.4
27.89	11.3

If the tuning factor T_w/T_n is between .8 and 1.4, then resonance effects are important and the amount of roll damping provided by the hull becomes very important in determining the roll amplitude. For T_w/T_n <.8 the vessel rolls very little. The likelihood that T_w/T_n is between .8 and 1.4 is large; therefore, a more detailed analysis is required to adequately account for the variables of hull shape and vertical center of gravity.

A report by Miller, et al.[C3] presents data for a DLG-9 destroyer and a LKA-113 Auxiliary. The characteristics for these ships are:

TABLE C3. SELECTED VESSEL CHARACTERISTICS

Vessel	Beam, feet	GM Range, Ft	GM/Beam	T_n = Natural Period, Sec
T-06	26.1	2.5 - 4.6	.10 - .18	7.26 - 5.35
WLM	33.0	2.0 - 3.0	.06 - .09	10.60 - 8.40
S-04	37.5	5.9 - 6.4	.16 - .17	6.80 - 6.50
AO-143	86.0	9.3 - 30.4	.11 - .35	12.40 - 6.90
T6-S-93a	90.0	10.0 - 36.0	.11 - .40	12.50 - 6.30
T8-S-100b	105.8	9.3 -	.09 -	15.20 -
WPB	18.0	3.15-	.18 -	4.46 -
WLM	31.5	6.86-	.22 -	5.29 -
YTM	27.0	2.11-	.18 -	8.18 -

Natural Period $\simeq 1.108\ k/\sqrt{GM}$ $\quad$ k = Radius of Gyration

Assume 1.108 k = .44 Beam.

Vessel	LBP	Beam	Draft	Displ. Long Ton	CB	GM	GM/Beam
DLG-9	490'	51.2'	17.9'	5,876	.45	4.7	0.09
LKA-113	550'	82.0'	25.5'	18,690	.57	5.3	0.10

The RMS roll amplitude in short-crested seas is given in Tables C4 and C5 for 0 and .07 Froude numbers for the five different sea states and at two different damping ratios, c/c_o.

The roll angles are given for the wave direction that produces the largest roll. For zero Froude number this is a beam sea. For higher Froude numbers the largest roll is produced by waves originating from aft of the beam.

2. Catamaran Responses

A survey of the various catamaran-type vessels designed or used for oil recovery shows that the LWLs range from 50 to 200 feet. Table C 6 gives estimates of the absolute motion at Station 1.5, the relative motion at Station 2.4, and the roll amplitude of each of three catamarans (LWL: 50, 100, 220 feet) in three sea conditions ($H_{1/3}$ = 6.89, 9.84, and 15.75 feet) denoting the relative seakeeping ability of these vessels. These estimates were made using spectral techniques. A paper by Hadler, et al[C4] provides nondimensional response curves for roll, absolute bow motions and relative bow motions for a 220-foot seagoing catamaran. Computed values of roll angle and relative bow motion lie near the middle of the corresponding measured full-scale values. (The measured values show considerable scatter in both cases). The full-scale measurements show roll angles in head seas which are as large as those in beam seas. The coupling in head seas between heave, pitch and roll is a result of the similar natural periods of these motions. Although the roll estimates only apply strictly to beam seas, they also indicate the order of magnitude of roll to be expected in head seas.

TABLE C4. DLG-9 - RMS ROLL AMPLITUDE - DEGREES

	$F_n = 0$		$F_n = .07$	
$H_{1/3}$/LBP	c/c_o = .04	.085	.05	0.1
.014	1.0	1.6	3.0	2.5
.020	7.0	4.5	7.0	4.5
.032	14.0	8.0	12.0	8.5
.040	18.0	12.0	14.0	11.0
.057	24.0	14.0	18.0	13.0

TABLE C5. AUXILIARY - RMS ROLL AMPLITUDES - DEGREES

	$F_n = 0$		$F_n = .07$	
$H_{1/3}$/LBP	c/c_o = 0.04	.085	.05	0.1
.013	1.0	1.0	1.5	1.0
.018	1.5	1.5	3.5	2.5
.029	6.0	4.0	7.5	5.0
.036	9.0	6.0	9.5	6.5
.051	16.0	10.0	14.0	9.0

TABLE C6. RMS AMPLITUDES OF CATAMARAN MOTIONS

	LWL = 220'			LWL = 100'			LWL = 50'		
Significant Wave Height*, ft	Roll Deg.	Sta.1.5 Abs.Mot., feet	Sta.2.4 Rel.Mot., feet	Roll Deg.	Sta. 1.5 Abs.Mot., feet	Sta.2.4 Rel.Mot., feet	Roll Deg.	Sta.1.5 Abs.Mot., feet	Sta.2.4 Rel.Mot., feet
6.89	3.7	4.2	3.8	7.4	4.3	3.4	9.1	3.1	2.1
9.84	5.4	6.8	5.8	8.6	5.2	3.9	9.7	3.6	2.1
15.75	7.6	9.8	7.8	9.3	6.4	4.1	10.2	4.8	2.2

* Pierson-Moskowitz Spectra

The roll motion shown in Table C6 is for beam seas only and the vertical motions are for head seas only. The 27.89-foot significant wave height produces extremely large motions for all vessels in the above LWL range; in these conditions survival is questionable. All results are for 10 knots forward speed. As can be seen from the monohull estimates, the motions in head seas are a function of forward speed; however, the roll in beam seas is practically independent of forward speed.

The 220-foot LWL catamaran is equivalent to the catamaran studied by Hadler, et al. This particular vessel has natural periods (six seconds to eight seconds) which correspond to the peak frequency of the random sea. Therefore, the 220-foot catamaran is excited near its resonance and has unusually large pitch and heave motions. The smaller catamarans have higher natural frequencies (farther from the exitation frequency) and, therefore, have smaller motions.

<u>References</u>:

C1. Loukakis, T. A., and C. Chryssostomidis, "Seakeeping Standard Series for Cruiser-Stern Ships," Transactions of the SNAME, Vol. 83, 1975.

C2. Cojeen, H. P., and C. R. Setterstrom, "Comparison of Head Seas Motions of 224-foot FY-75 AFT (Round-Bottom Hull Form) and 194-foot Offshore Supply Boat (Hard-Chine Hull Form)," Hydronautics, Inc., Technical Report 7401.08-1, January 1974.

C3. Miller, E. R., G. C. Nickum, J. R. Rudnicki, B. J. Young, "Task 1 Report on Evaluation of Current Towing Vessel Stability Criterion and Proposed Fishing Vessel Stability Criteria," Hydronautics, Inc., Technical Report 7311-1, July 1974.

C4. Hadler, J. B., C. M. Lee, J. T. Birmingham, and H. O. Jones, "Ocean Catamaran Seakeeping Design, Based on the Experiences of <u>USNS Hayes</u>," SNAME Trans., Vol. 82, p. 126, 1974.

APPENDIX D

Time-Line Diagrams

1. Cargo off-loading Using Portable Pumping Systems
2. Ship Ballasting Using Portable Water Pumping Systems
3. Vessel of Opportunity Skimming System (VOSS)
4. Dedicated Skimmer
5. Skimmer Independent of Barrier or Skimmer Part of Barrier
6. Vessel-Applied Dispersant System
7. Aircraft-Applied Dispersant System

Tasks are depicted as labeled lines with arrows leading to other tasks. The circle at the left end of a task line represents the beginning of that task and the circle at the right end is the point of completion. The length of task lines has no significance. Tasks which can be performed simultaneously appear parallel on the time-line chart. For example, in the diagram of cargo off-loading using portable pumps, locating an ocean tug for charter, and notifying personnel with assessment gear to fly to the staging area, can both be carried out independently. Some tasks are dependent and cannot be started until certain other tasks are completed. Such tasks appear in series. For example, in the off-loading diagram, the assessment personnel cannot be flown to the tanker until the assessment gear has been prepared and a helicopter has arrived to transport them.

Example times for the completion of each task appear beneath each task line. These times are estimates based on the specific situation being responded to. The heavy dotted line is the critical path or longest route through the operation. The sum of the task times on the critical path is the total "Time required" to complete the operation.

The first two time-lines, Cargo Off-loading using Portable Pumping Systems and Ship Ballasting using Portable Water Pumping Systems, are based on the following stranded scenario.

1. Oil Viscosity: Medium crude - 30 cs (0.87 s.g.)
2. Sea Conditions: Operate: 10 m/sec wind, $H_{1/3} = 2.1$ m
   Survive: 15 m/sec wind, $H_{1/3} = 4.8$ m
3. Oil Quantity: 100,000-DWT Tanker
4. Other Casualty Features:
   - Location: 25 miles offshore, 50 miles from nearest staging area, 200 miles from nearest major supply center

- Vessel grounded - holed - speed at grounding approx. 8 knots
- Vessel power systems inoperative
- List 10^{o}
- Trim negligible

5. Other Environmental Features;
   - Diurnal tidal current of 2 kts maximum
   - Tide range is 1 m
   - Sea Temperature $4^{o}C$
   - Air Temperature $0^{o}C$
   - Intermittent precipitation
   - Minimal debris present

It was assumed for development of the Cargo Off-loading diagram that the receiving vessel would be moored to the stranded ship as depicted in Figure 2 (main body of report).

The time lines for skimming and dispersant systems are based on the same stranding scenario but with the following special spill conditions.

Oil Rate: 1000 gpm average outflow rate

Other Slick features:

- At 1 mile from source: thin slick, 2000 ft. wide, with thickness 0.03 mm; 400 ft. wide windrow in center of slick, containing elongated oil pancakes 5 mm thick and 100 x 200 ft. in area (90% of oil)
- Wind/wave driven slick velocity 0.7 kts, in addition to tidal current of 2 kts. max.

Other Casualty features:

- Vessel grounded and holed

Additional assumptions made in developing the skimming and redistribution time-lines are listed below.

Vessel of Opportunity Skimming System

1. Two barges are used to receive recovered oil
2. Skimming vessel tows storage barge

Dedicated Skimmer

1. Two barges are used to receive recovered oil
2. Skimmer off-loads periodically to barge while underway

Skimmer Independent of Barrier and Skimmer Part of Barrier

1. Two barges used to receive recovered oil.
2. Skimmer and boom are deployed from supply boat with a stern "A" frame.
3. Launching supply boat follows boom, towing the receiving barge, and supporting the skimmer power supply and hoses

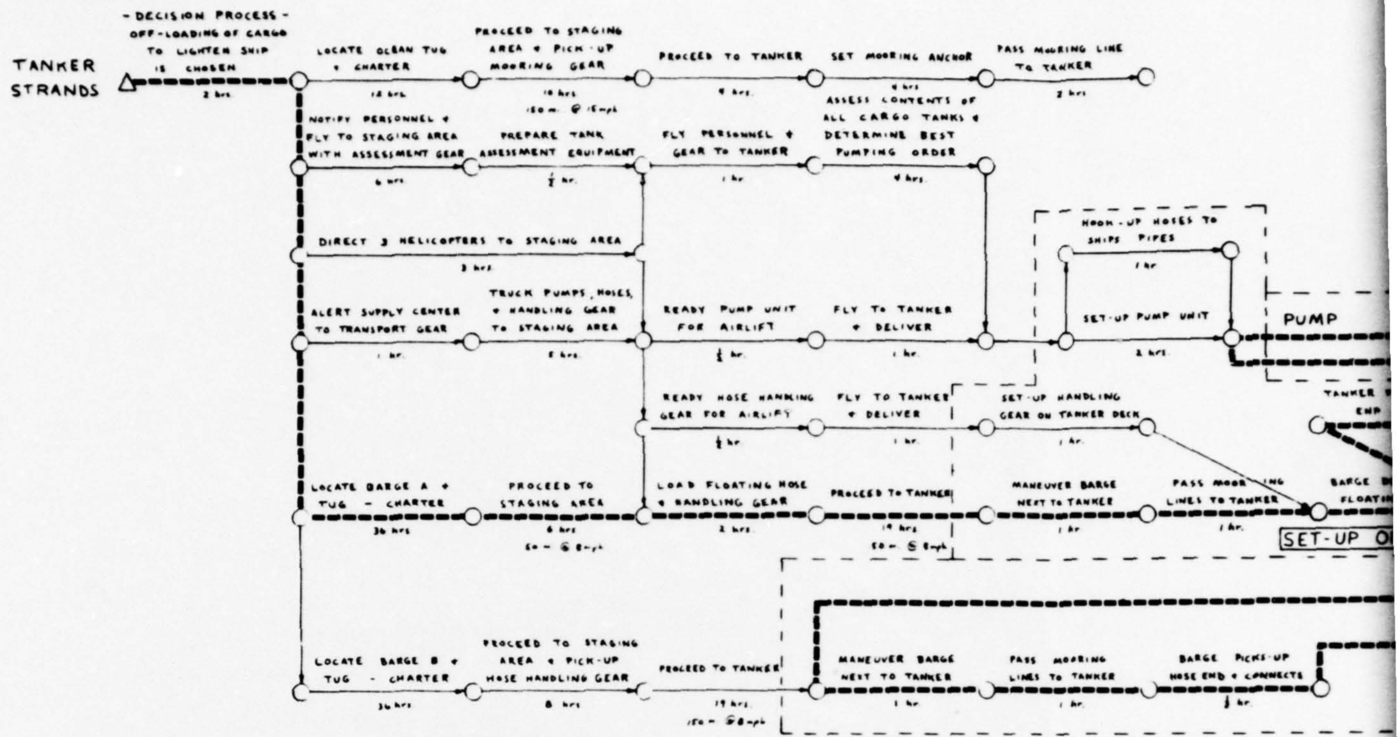
Vessel-Applied Dispersant System

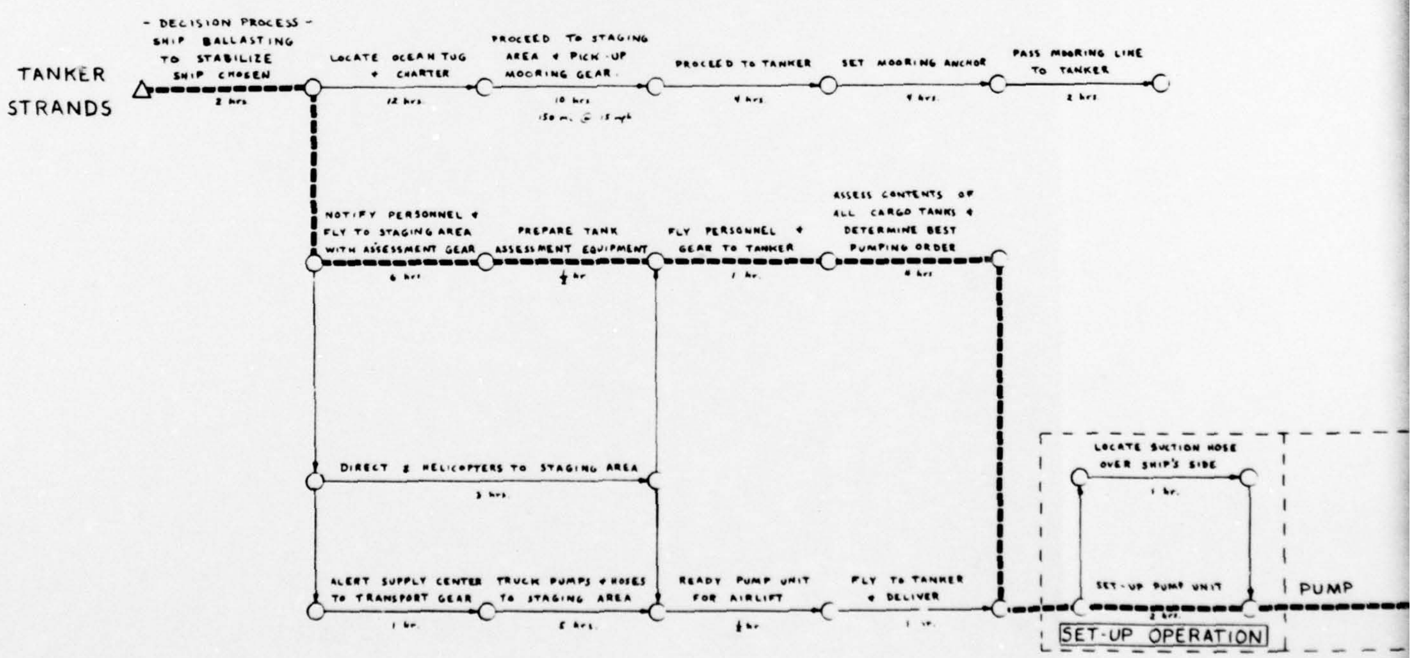
1. Dispersants are stored at supply centers in barges.
2. Supply boats with tankage for dispersants are used as spray vessels.
3. Spray boats refill at sea from dispersant barge.

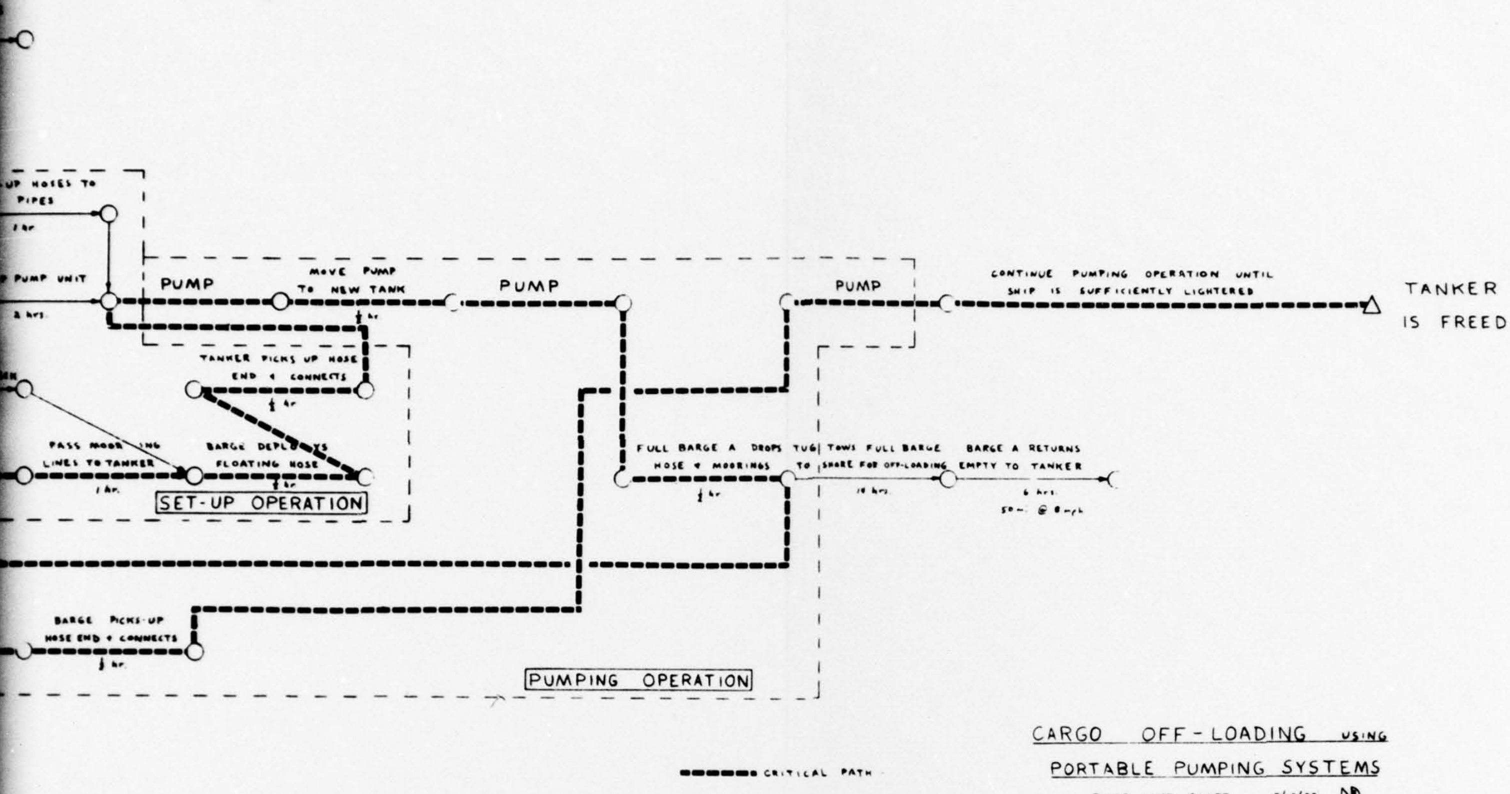
Aircraft-Applied Dispersant System

1. Dispersants are stored at supply centers in barges.
2. Barges transport dispersants to port near staging airfield.
3. Tank trucks transport dispersants from barges to airfield.
4. Large 4-engine aircraft are used as spray planes.
5. Rapid aircraft refill system is used.

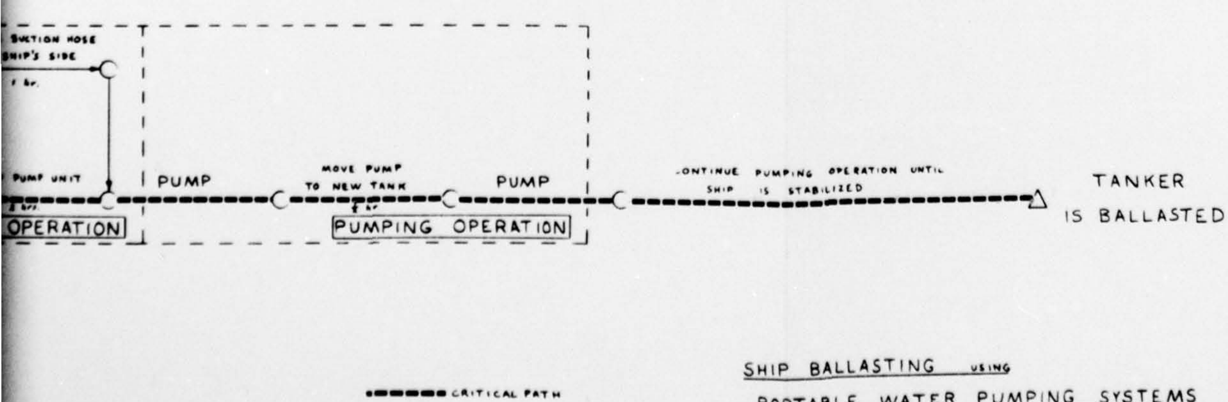
* U.S. GOVERMENT PRINTING OFFICE : 1978 0-621-036/137


TANKER STRANDS
- DECISION PROCESS - OFF-LOADING OF CARGO TO LIGHTEN SHIP IS CHOSEN
2 hrs.
LOCATE OCEAN TUG + CHARTER
12 hrs.
PROCEED TO STAGING AREA + PICK-UP MOORING GEAR
10 hrs. 150 mi. @ 15 mph
PROCEED TO TANKER
4 hrs.
SET MOORING ANCHOR
4 hrs.
PASS MOORING LINE TO TANKER
2 hrs.
NOTIFY PERSONNEL + FLY TO STAGING AREA WITH ASSESSMENT GEAR
6 hrs.
PREPARE TANK ASSESSMENT EQUIPMENT
½ hr.
FLY PERSONNEL + GEAR TO TANKER
1 hr.
ASSESS CONTENTS OF ALL CARGO TANKS + DETERMINE BEST PUMPING ORDER
4 hrs.
DIRECT 3 HELICOPTERS TO STAGING AREA
3 hrs.
ALERT SUPPLY CENTER TO TRANSPORT GEAR
1 hr.
TRUCK PUMPS, HOSES, + HANDLING GEAR TO STAGING AREA
5 hrs.
READY PUMP UNIT FOR AIRLIFT
½ hr.
FLY TO TANKER + DELIVER
1 hr.
HOOK-UP HOSES TO SHIPS PIPES
1 hr.
SET-UP PUMP UNIT
2 hrs.
PUMP
READY HOSE HANDLING GEAR FOR AIRLIFT
½ hr.
FLY TO TANKER + DELIVER
1 hr.
SET-UP HANDLING GEAR ON TANKER DECK
1 hr.
LOCATE BARGE A + TUG - CHARTER
36 hrs.
PROCEED TO STAGING AREA
6 hrs. 50 mi. @ 8 mph
LOAD FLOATING HOSE + HANDLING GEAR
2 hrs.
PROCEED TO TANKER
19 hrs. 50 mi. @ 8 mph
MANEUVER BARGE NEXT TO TANKER
1 hr.
PASS MOORING LINES TO TANKER
1 hr.
SET-UP O
LOCATE BARGE B + TUG - CHARTER
36 hrs.
PROCEED TO STAGING AREA + PICK-UP HOSE HANDLING GEAR
8 hrs.
PROCEED TO TANKER
19 hrs. 150 mi. @ 8 mph
MANEUVER BARGE NEXT TO TANKER
1 hr.
PASS MOORING LINES TO TANKER
1 hr.
BARGE PICKS-UP HOSE END + CONNECTS
½ hr.


TANKER STRANDS
- DECISION PROCESS - SHIP BALLASTING TO STABILIZE SHIP CHOSEN
2 hrs.
LOCATE OCEAN TUG + CHARTER
12 hrs.
PROCEED TO STAGING AREA + PICK-UP MOORING GEAR
10 hrs. 150 mi. @ 15 mph
PROCEED TO TANKER
4 hrs.
SET MOORING ANCHOR
4 hrs.
PASS MOORING LINE TO TANKER
2 hrs.
NOTIFY PERSONNEL + FLY TO STAGING AREA WITH ASSESSMENT GEAR
6 hrs.
PREPARE TANK ASSESSMENT EQUIPMENT
½ hr.
FLY PERSONNEL + GEAR TO TANKER
1 hr.
ASSESS CONTENTS OF ALL CARGO TANKS + DETERMINE BEST PUMPING ORDER
4 hrs.
DIRECT 3 HELICOPTERS TO STAGING AREA
3 hrs.
ALERT SUPPLY CENTER TO TRANSPORT GEAR
1 hr.
TRUCK PUMPS + HOSES TO STAGING AREA
5 hrs.
READY PUMP UNIT FOR AIRLIFT
½ hr.
FLY TO TANKER + DELIVER
1 hr.
LOCATE SUCTION HOSE OVER SHIP'S SIDE
1 hr.
SET-UP PUMP UNIT
2 hrs.
PUMP
SET-UP OPERATION

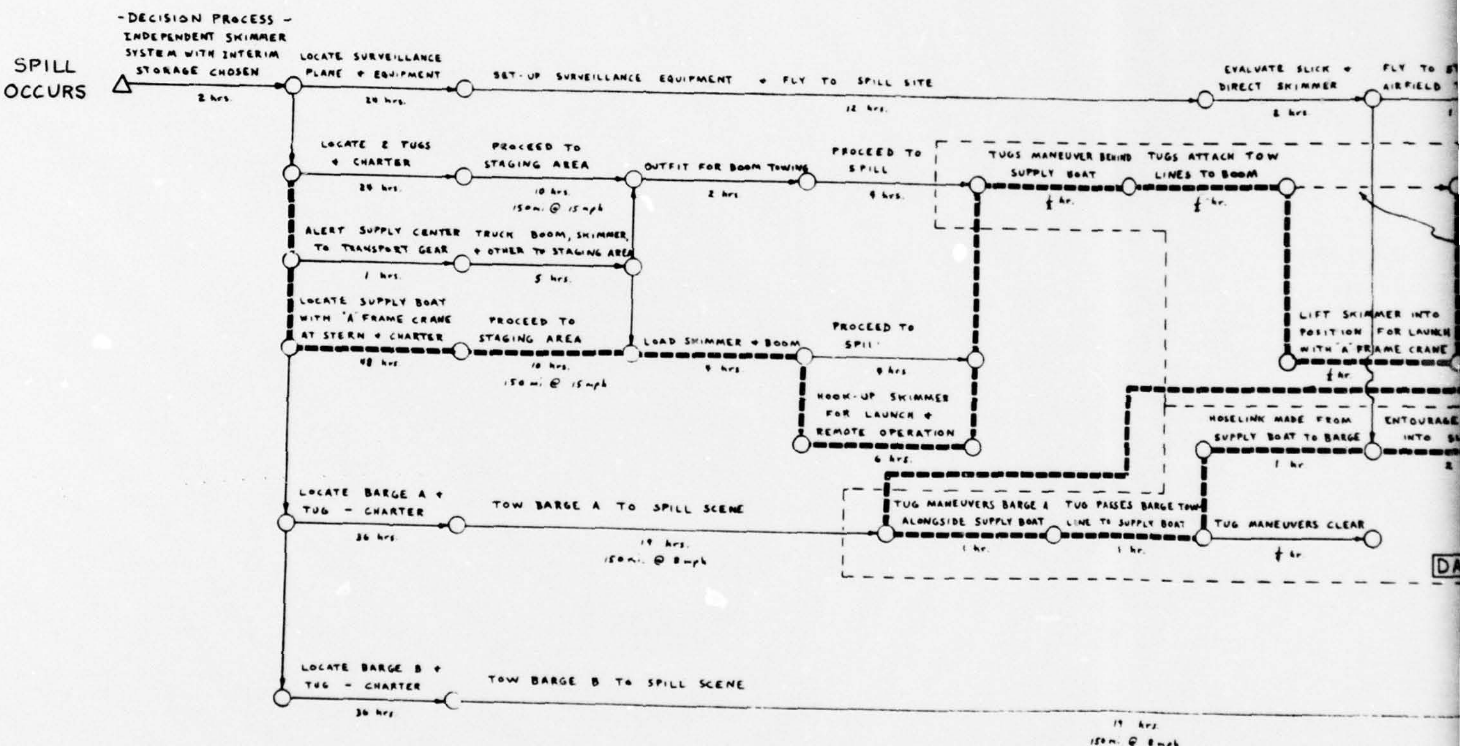


CARGO OFF-LOADING USING
PORTABLE PUMPING SYSTEMS
TIME LINE CHART 5/10/78 ND

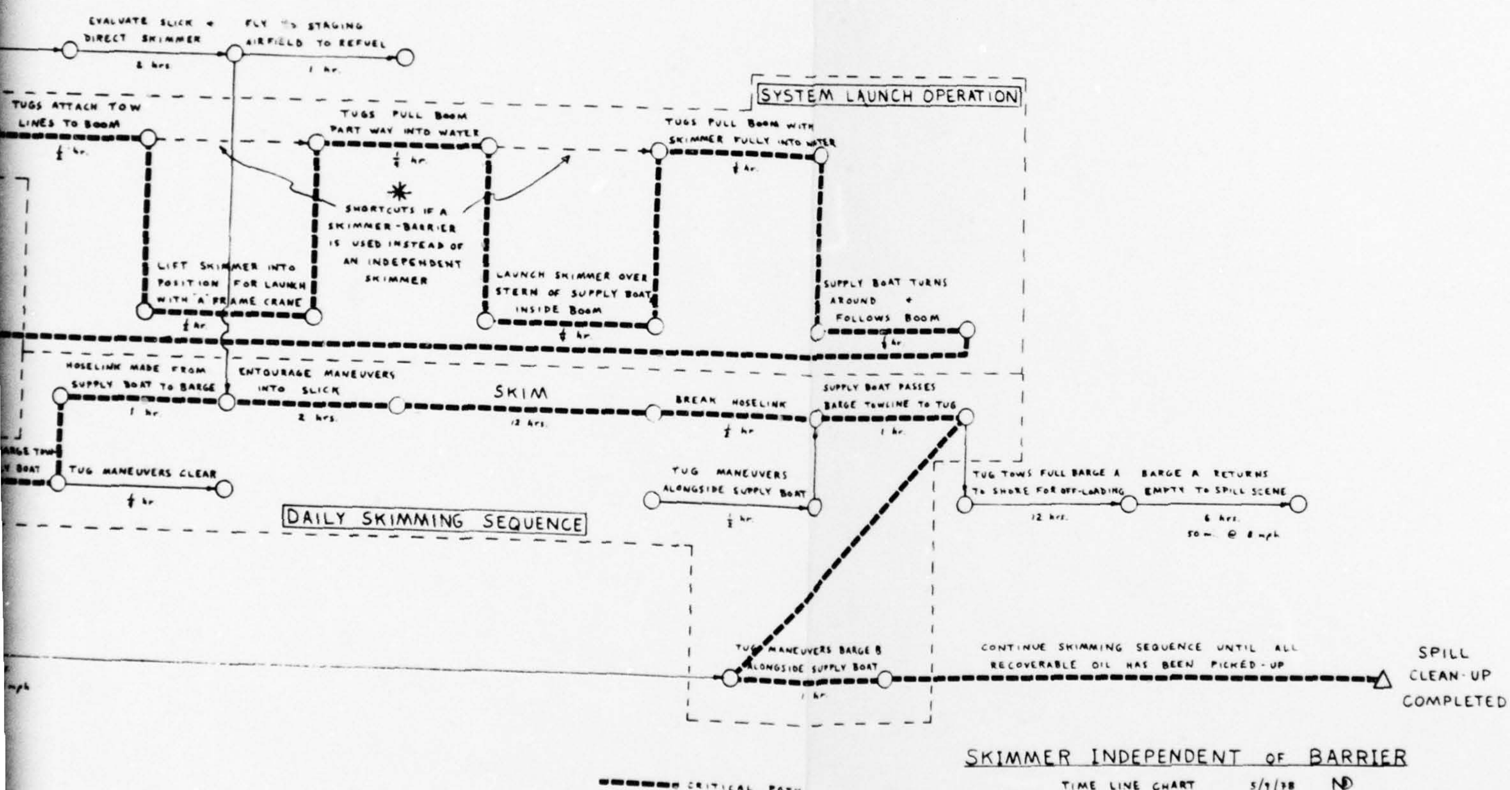


SHIP BALLASTING USING
PORTABLE WATER PUMPING SYSTEMS
TIME LINE CHART 5/11/78 ND

2



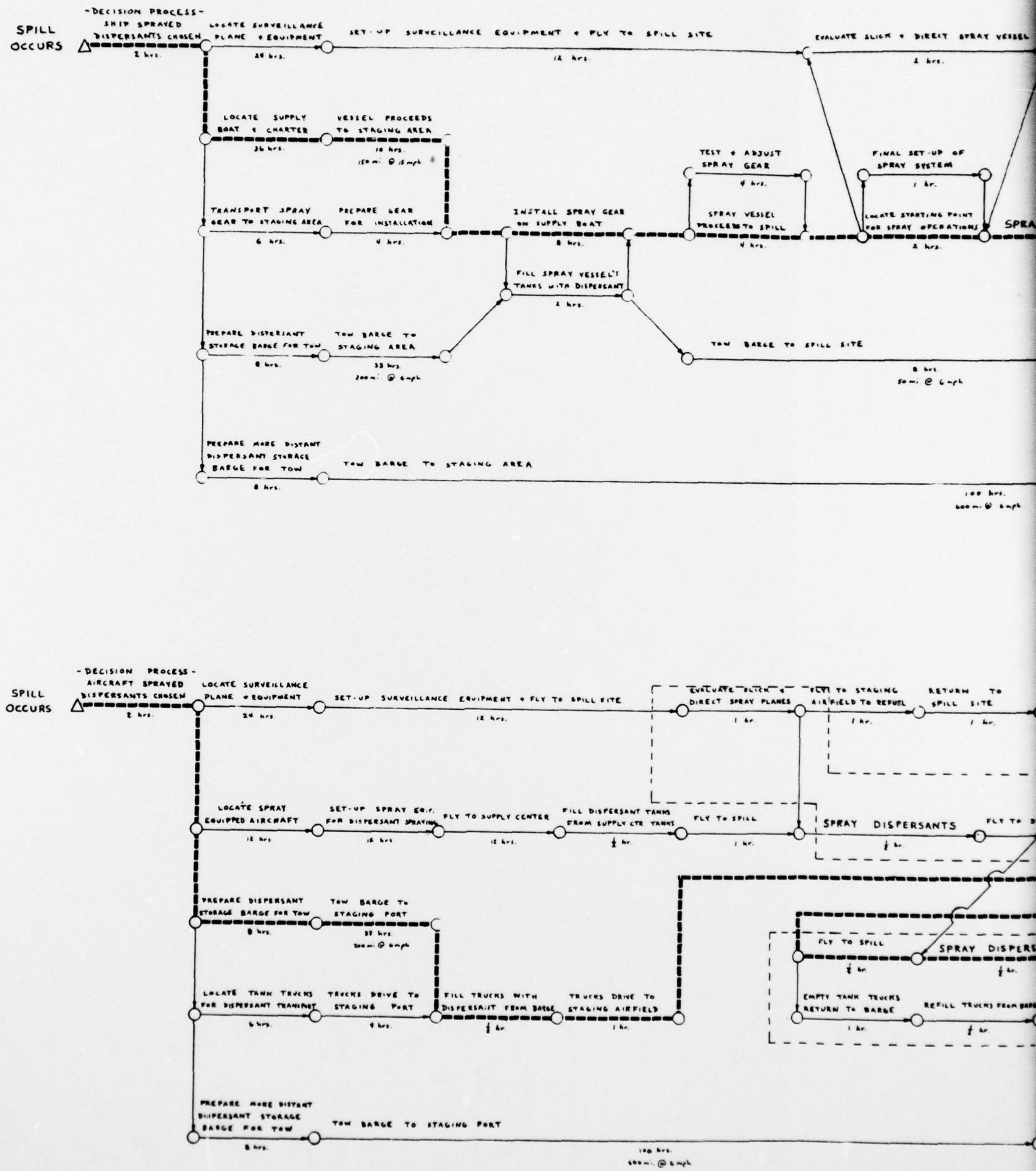
SPILL OCCURS
-DECISION PROCESS -
INDEPENDENT SKIMMER SYSTEM WITH INTERIM STORAGE CHOSEN
2 hrs.
LOCATE SURVEILLANCE PLANE + EQUIPMENT
24 hrs.
SET-UP SURVEILLANCE EQUIPMENT + FLY TO SPILL SITE
12 hrs.
EVALUATE SLICK + DIRECT SKIMMER
2 hrs.
FLY TO
AIRFIELD
LOCATE 2 TUGS + CHARTER
24 hrs.
PROCEED TO STAGING AREA
10 hrs.
150 mi. @ 15 mph
OUTFIT FOR BOOM TOWING
2 hrs
PROCEED TO SPILL
9 hrs.
TUGS MANEUVER BEHIND SUPPLY BOAT
TUGS ATTACH TOW LINES TO BOOM
ALERT SUPPLY CENTER TO TRANSPORT GEAR
1 hrs.
TRUCK BOOM, SKIMMER, + OTHER TO STAGING AREA
5 hrs.
LOCATE SUPPLY BOAT WITH 'A' FRAME CRANE AT STERN + CHARTER
48 hrs.
PROCEED TO STAGING AREA
10 hrs.
150 mi. @ 15 mph
LOAD SKIMMER + BOOM
9 hrs
PROCEED TO SPILL
9 hrs
HOOK-UP SKIMMER FOR LAUNCH + REMOTE OPERATION
6 hrs.
LIFT SKIMMER INTO POSITION FOR LAUNCH WITH 'A' FRAME CRANE
HOSELINK MADE FROM SUPPLY BOAT TO BARGE
1 hr.
ENTOURAGE
INTO
LOCATE BARGE A + TUG - CHARTER
36 hrs.
TOW BARGE A TO SPILL SCENE
19 hrs.
150 mi. @ 8 mph
TUG MANEUVERS BARGE A ALONGSIDE SUPPLY BOAT
1 hr.
TUG PASSES BARGE TOW LINE TO SUPPLY BOAT
1 hr.
TUG MANEUVERS CLEAR
LOCATE BARGE B + TUG - CHARTER
36 hrs.
TOW BARGE B TO SPILL SCENE
19 hrs.
150 mi. @ 8 mph

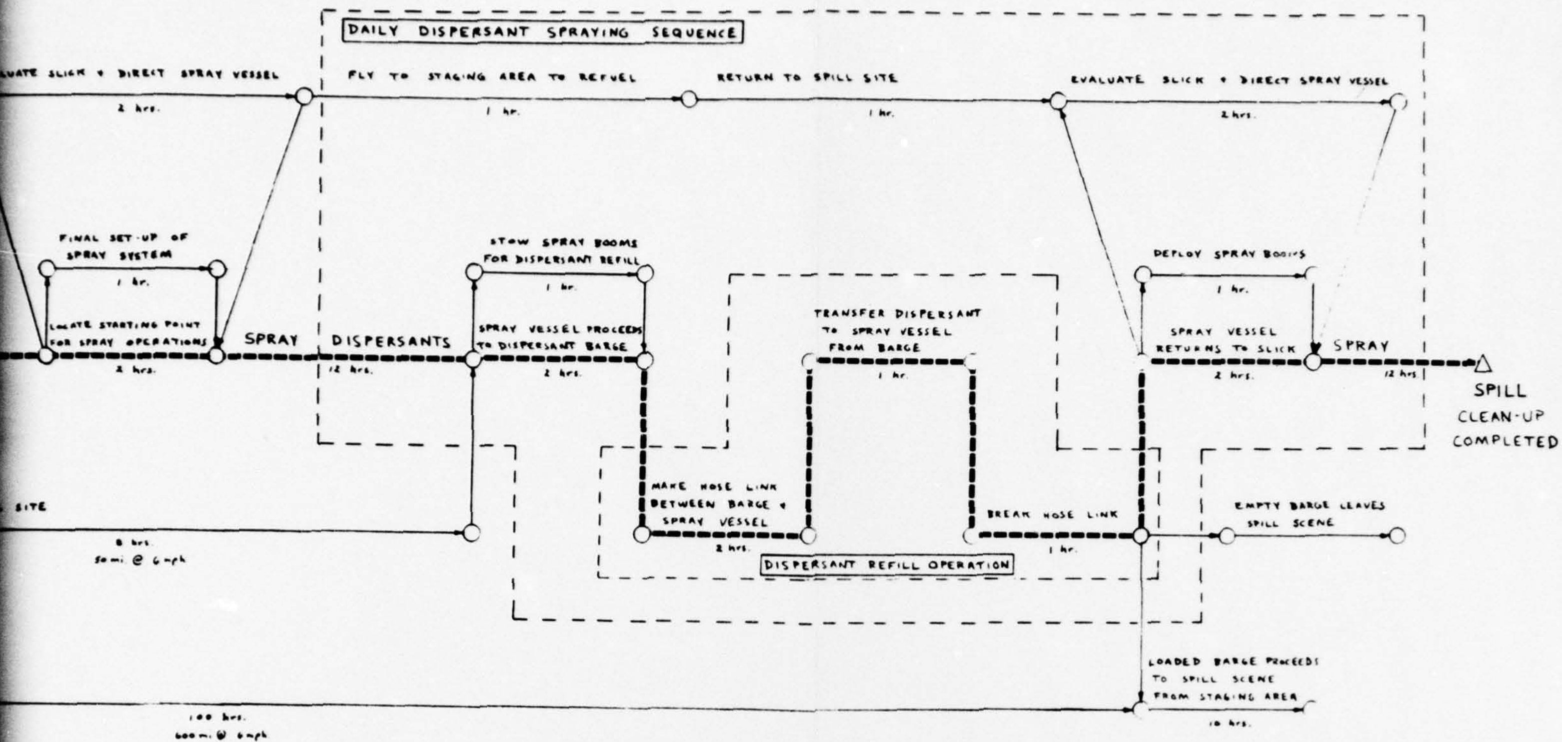


SKIMMER INDEPENDENT OF BARRIER

TIME LINE CHART 5/9/78 ND

(* APPLIES TO SKIMMER PART OF BARRIER)

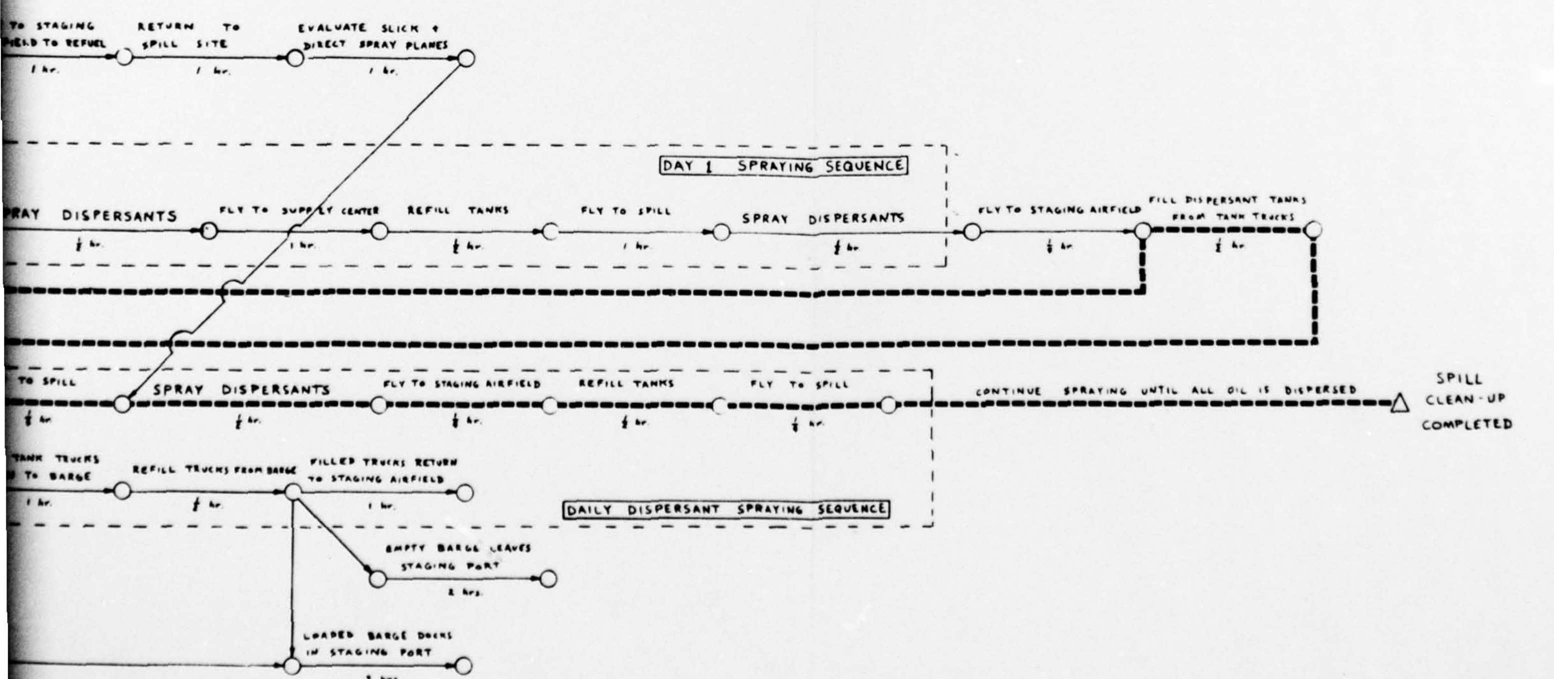

SPILL OCCURS
-DECISION PROCESS-
SHIP SPRAYED DISPERSANTS CHOSEN
2 hrs.
LOCATE SURVEILLANCE PLANE + EQUIPMENT
24 hrs.
SET-UP SURVEILLANCE EQUIPMENT + FLY TO SPILL SITE
12 hrs.
EVALUATE SLICK + DIRECT SPRAY VESSEL
2 hrs.
LOCATE SUPPLY BOAT + CHARTER
36 hrs.
VESSEL PROCEEDS TO STAGING AREA
10 hrs.
150 mi. @ 15 mph
TEST + ADJUST SPRAY GEAR
4 hrs.
FINAL SET-UP OF SPRAY SYSTEM
1 hr.
TRANSPORT SPRAY GEAR TO STAGING AREA
6 hrs.
PREPARE GEAR FOR INSTALLATION
4 hrs.
INSTALL SPRAY GEAR ON SUPPLY BOAT
8 hrs.
SPRAY VESSEL PROCEEDS TO SPILL
4 hrs.
LOCATE STARTING POINT FOR SPRAY OPERATIONS
2 hrs.
SPRA
FILL SPRAY VESSEL'S TANKS WITH DISPERSANT
2 hrs.
PREPARE DISPERSANT STORAGE BARGE FOR TOW
8 hrs.
TOW BARGE TO STAGING AREA
33 hrs.
200 mi. @ 6 mph
TOW BARGE TO SPILL SITE
8 hrs.
50 mi. @ 6 mph
PREPARE MORE DISTANT DISPERSANT STORAGE BARGE FOR TOW
8 hrs.
TOW BARGE TO STAGING AREA
100 hrs.
600 mi. @ 6 mph
SPILL OCCURS
-DECISION PROCESS-
AIRCRAFT SPRAYED DISPERSANTS CHOSEN
2 hrs.
LOCATE SURVEILLANCE PLANE + EQUIPMENT
24 hrs.
SET-UP SURVEILLANCE EQUIPMENT + FLY TO SPILL SITE
12 hrs.
EVALUATE SLICK + DIRECT SPRAY PLANES
1 hr.
FLY TO STAGING AIRFIELD TO REFUEL
1 hr.
RETURN TO SPILL SITE
1 hr.
LOCATE SPRAY EQUIPPED AIRCRAFT
12 hrs.
SET-UP SPRAY EQ. FOR DISPERSANT SPRAYING
18 hrs.
FLY TO SUPPLY CENTER
12 hrs.
FILL DISPERSANT TANKS FROM SUPPLY CTR TANKS
½ hr.
FLY TO SPILL
1 hr.
SPRAY DISPERSANTS
½ hr.
FLY TO
PREPARE DISPERSANT STORAGE BARGE FOR TOW
8 hrs.
TOW BARGE TO STAGING PORT
33 hrs.
200 mi. @ 6 mph
FLY TO SPILL
¼ hr.
SPRAY DISPERSA
½ hr.
LOCATE TANK TRUCKS FOR DISPERSANT TRANSPORT
6 hrs.
TRUCKS DRIVE TO STAGING PORT
4 hrs.
FILL TRUCKS WITH DISPERSANT FROM BARGE
½ hr.
TRUCKS DRIVE TO STAGING AIRFIELD
1 hr.
EMPTY TANK TRUCKS RETURN TO BARGE
1 hr.
REFILL TRUCKS FROM BARGE
½ hr.
PREPARE MORE DISTANT DISPERSANT STORAGE BARGE FOR TOW
8 hrs.
TOW BARGE TO STAGING PORT
100 hrs.
600 mi. @ 6 mph
/



CRITICAL PATH

VESSEL-APPLIED DISPERSANT SYSTEM

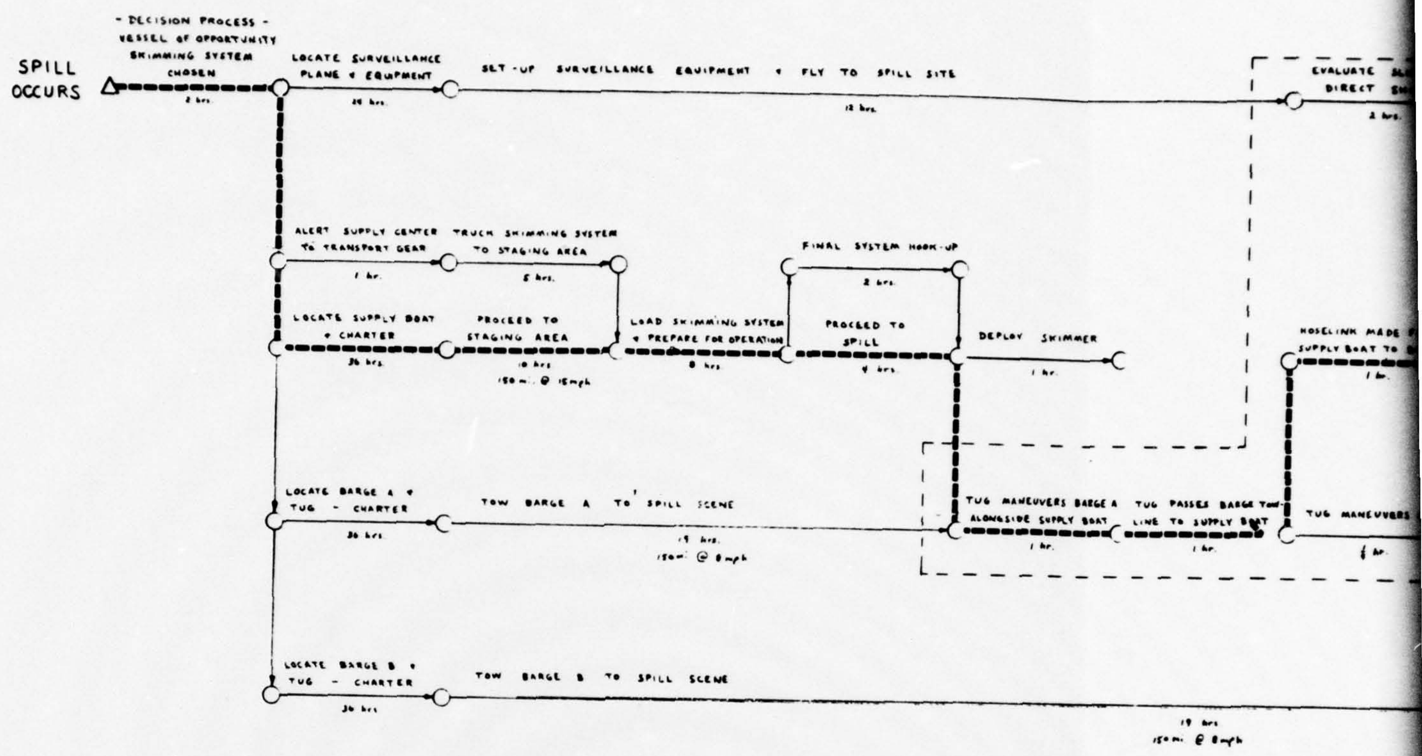
TIME LINE CHART 5/5/78 ND

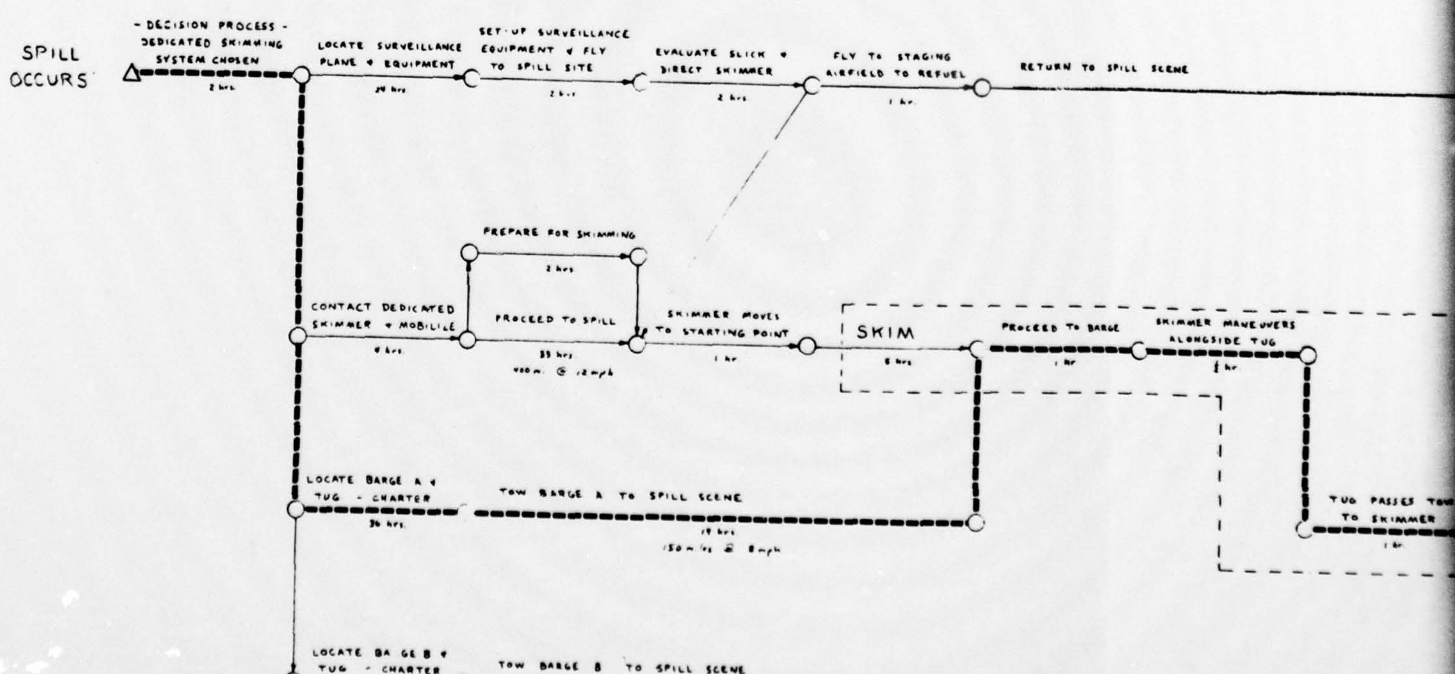


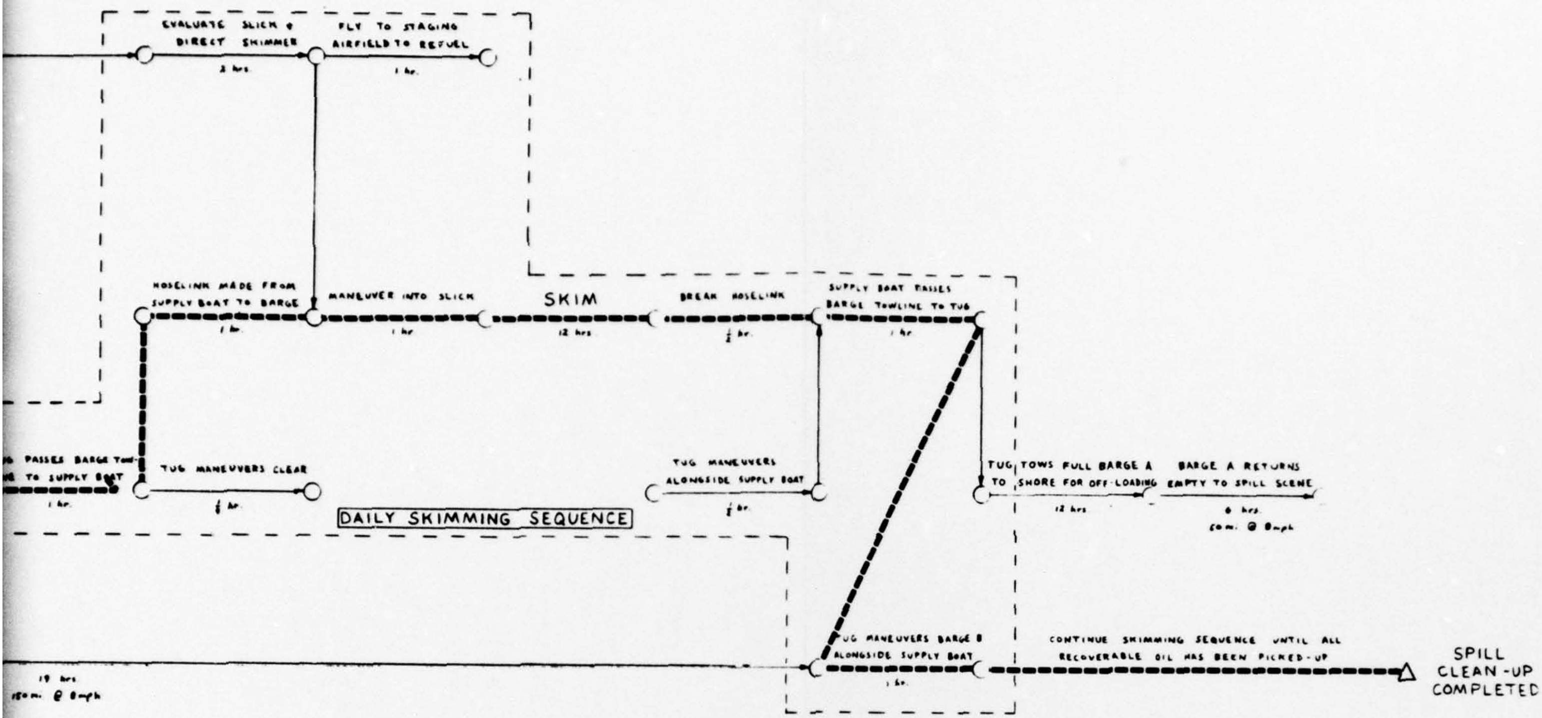
CRITICAL PATH

AIRCRAFT-APPLIED DISPERSANT SYSTEM

TIME LINE CHART 5/8/78 ND


SPILL OCCURS
- DECISION PROCESS -
VESSEL OF OPPORTUNITY SKIMMING SYSTEM CHOSEN
2 hrs.
LOCATE SURVEILLANCE PLANE + EQUIPMENT
SET-UP SURVEILLANCE EQUIPMENT + FLY TO SPILL SITE
12 hrs.
ALERT SUPPLY CENTER TO TRANSPORT GEAR
1 hr.
TRUCK SKIMMING SYSTEM TO STAGING AREA
5 hrs.
LOCATE SUPPLY BOAT + CHARTER
PROCEED TO STAGING AREA
150 mi. @ 15mph
LOAD SKIMMING SYSTEM + PREPARE FOR OPERATION
FINAL SYSTEM HOOK-UP
2 hrs.
PROCEED TO SPILL
DEPLOY SKIMMER
1 hr.
LOCATE BARGE A + TUG - CHARTER
TOW BARGE A TO SPILL SCENE
150mi @ 8mph
TUG MANEUVERS BARGE A ALONGSIDE SUPPLY BOAT
1 hr.
TUG PASSES BARGE TOW LINE TO SUPPLY BOAT
1 hr.
LOCATE BARGE B + TUG - CHARTER
TOW BARGE B TO SPILL SCENE
150mi. @ 8mph

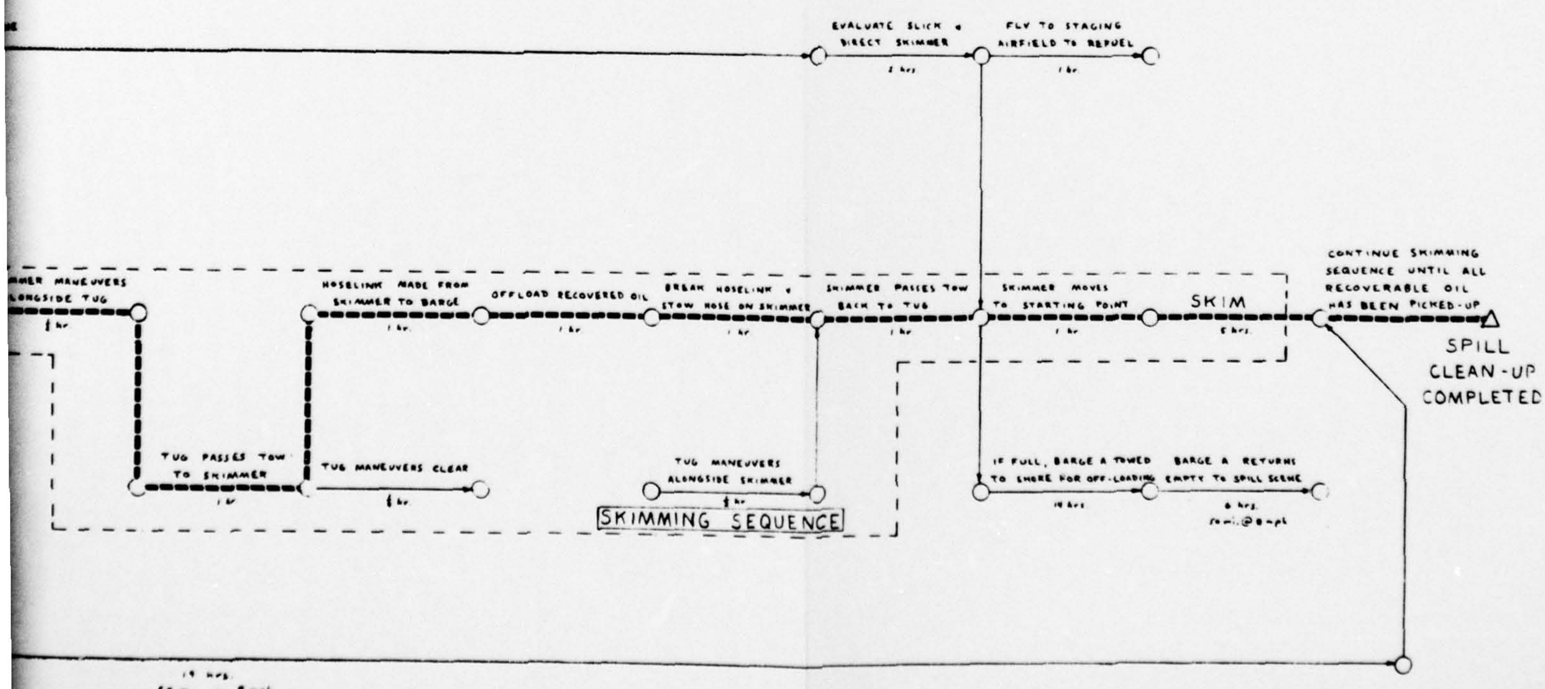

SPILL OCCURS
- DECISION PROCESS -
DEDICATED SKIMMING SYSTEM CHOSEN
2 hrs.
LOCATE SURVEILLANCE PLANE + EQUIPMENT
SET-UP SURVEILLANCE EQUIPMENT + FLY TO SPILL SITE
EVALUATE SLICK + DIRECT SKIMMER
2 hrs.
FLY TO STAGING AIRFIELD TO REFUEL
1 hr.
RETURN TO SPILL SCENE
PREPARE FOR SHIMMING
2 hrs.
CONTACT DEDICATED SKIMMER + MOBILIZE
PROCEED TO SPILL
SKIMMER MOVES TO STARTING POINT
1 hr.
SKIM
PROCEED TO BARGE
SKIMMER MANEUVERS ALONGSIDE TUG
LOCATE BARGE A + TUG - CHARTER
TOW BARGE A TO SPILL SCENE
TUG PASSES TOW LINE TO SKIMMER
1 hr.
LOCATE BARGE B + TUG - CHARTER
TOW BARGE B TO SPILL SCENE



CRITICAL PATH

VESSEL of OPPORTUNITY SKIMMING SYSTEM (VOSS)

TIME LINE CHART 5/15/78 ND



CRITICAL PATH

DEDICATED SKIMMER

TIME LINE CHART 5/15/78 ND

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